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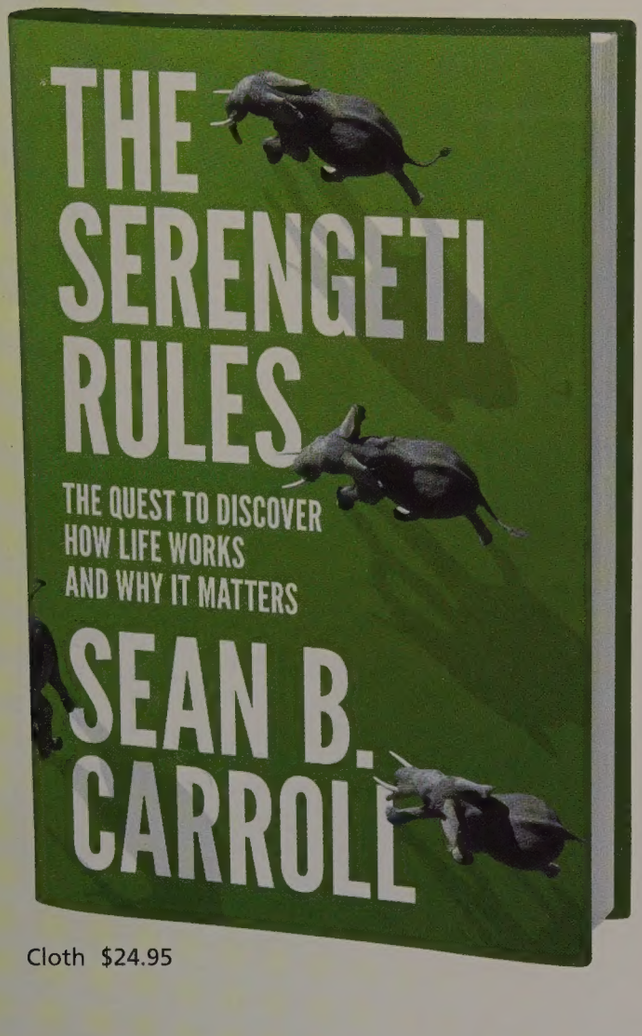

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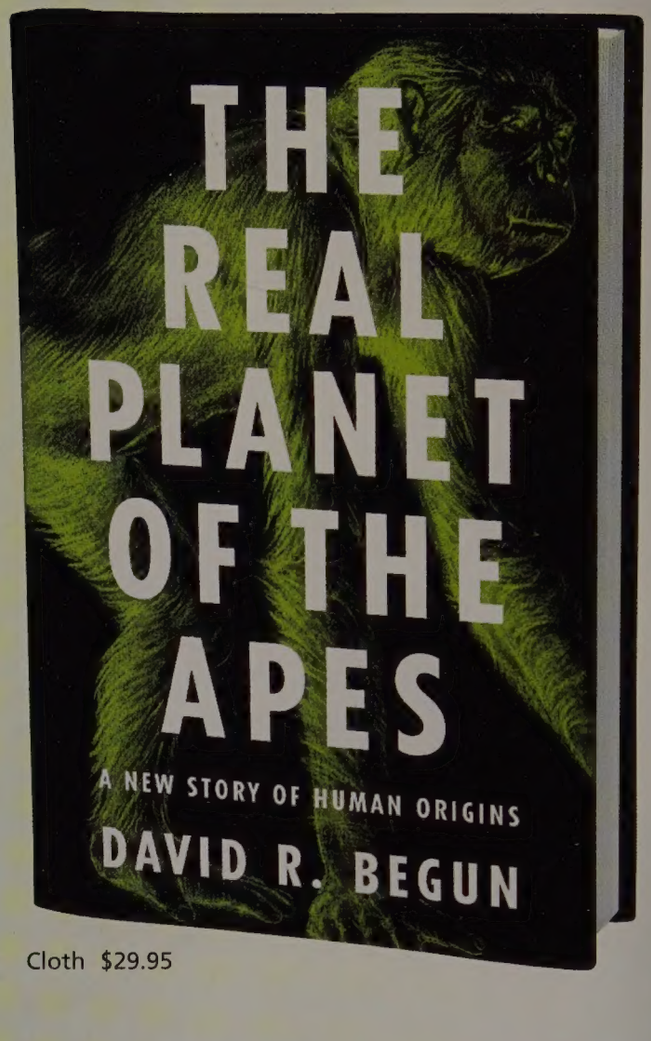

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"A masterful book by a leading scholar. . . . *The Real Planet of the Apes* is punctuated with wonderful bits of paleontological history and anecdotes about Begun's own experiences in the field. No other book covers the topic in such a coherent and comprehensive way."
—John G. Fleagle, author of *Primate Adaptation and Evolution*

"Enthralling."
—Steven Mithen, *New York Review of Books*

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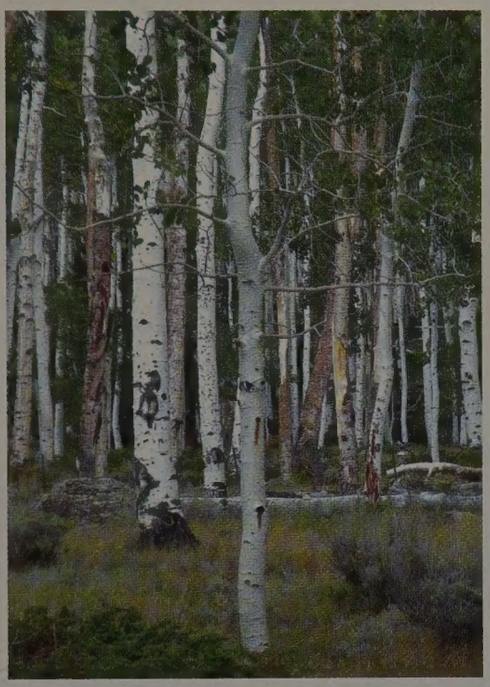
MARCH 2016 VOLUME 124 NUMBER 2

FEATURES

14 THE LIFE OF A LAKE
Geological events have made the Dead Sea geographically and chemically unique.
BY BARBARA KREIGER

22 FEATHERS
A photo essay displays brilliant plumage.
BY ROBERT CLARK



26 WHEEL VERSUS WHEEL
Advances in transportation required disparate wheel designs.
BY RICHARD W. BULLIET

32 SAVING PANDO
Humans are taking measured steps to rejuvenate an ailing giant.
BY PAUL C. ROGERS

DEPARTMENTS

2 THE NATURAL MOMENT
In Its Father's Footsteps
Photograph by Thomas D. Mangelsen

5 nature.net
Bubble Baths

6 SAMPLINGS

10 NATURALIST AT LARGE
Blue Jays in Touch
Bernd Heinrich

20 FIELD NOTES
Evidence of Early Takeoff
Luis M. Chiappe

38 EXPLORING SCIENCE AND NATURE

42 THIS LAND
Marine Remains in the Mountains
Robert H. Mohlenbrock

45 SKYLOG
Dates Uncertain
Joe Rao

46 BOOKSHELF
Laurence A. Marschall

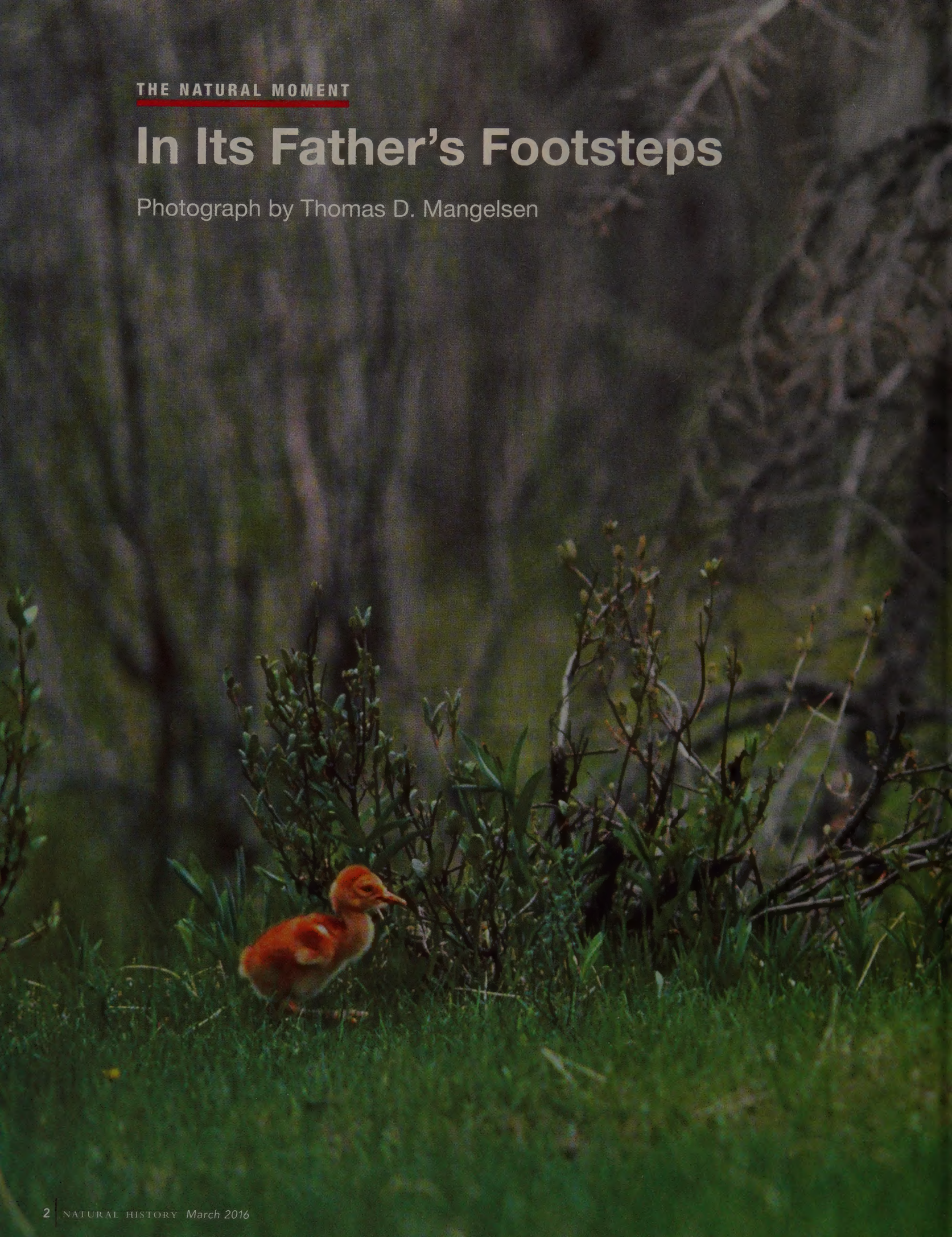
48 ENDPAPER
State-sponsored Happiness
Karen Greenspan

ON THE COVER: *The whooping crane (*Grus americana*) is the tallest bird in North America and one of the most imposing, especially when it assumes a threatening posture. After near extinction in the 1940s, it has shown limited recovery as a result of concerted conservation measures.*
Photograph by Thomas D. Mangelsen

THE NATURAL MOMENT

In Its Father's Footsteps

Photograph by Thomas D. Mangelsen



◄ *See preceding two pages*

Revered for centuries by cultures across the globe, cranes are thought to be among the oldest living bird clades. Of the fifteen species of cranes, only two, the sandhill crane (*Grus canadensis*) and the whooping crane (*Grus americana*), are found in North America.

Sandhill cranes mate for life and breed once a year, typically laying two eggs each spring. At the start of nesting season, parents-to-be prepare by building a platform-like nest in marshes or shallow ponds. Nests can be five-to-six feet in diameter and require continual maintenance to prevent flooding.

During the thirty-day incubation period, parents take turns warming the eggs while the other forages for food and nest-building materials. The eggs typically hatch within a day or two of each other, and the chicks are able to walk and swim within hours.

Photographer Mangelsen captured this image of a sandhill crane parent teaching its day-old chick to hunt while waiting for its sibling to hatch near the Buffalo Fork of the Snake River in Wyoming's Grand Teton National Park.

Once the second chick is able to move and hunt on its own, the crane family leaves the nest, never to return. Chicks remain with their parents for about a year, until the parents are ready to mate again.

Around this time the cranes begin "painting" their gray plumage a dark reddish-brown, preening with iron-rich sediment they pick up in their beaks from pond bottoms. Cranes continue this behavior from early spring until their winter molt, staining their entire bodies except for their upper necks, which are out of reach. This unique behavior may provide camouflage.

Nature photographer **Thomas D. Mangelsen** has traveled throughout the world for nearly forty years, observing and photographing the earth's last great wild places. He has been named Conservation Photographer of the Year by *Nature's Best Photography*, the BBC's Wildlife Photographer of the Year, and the Outstanding Nature Photographer of the Year by the North American Nature Photography Association. Mangelsen's entire portfolio can be viewed online at www.mangelsen.com.

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Bubble Baths

Forget the soap and soaks.

Aggressive agitation may be just as effective at washing away dirt as is soap or any other product you might add to your bath water. You, or those who market fresh produce, may even be able to rid fruits and vegetables of pathogens, such as *E. coli* and *Salmonella,* without the use of chemicals. The bursting of cavitation bubbles, which are created when air is churned up in water, has a suction effect that pulls dirt and everything else nearby toward the collapsed bubbles. Cavitation bubbles are already in use for certain industrial applications, such as cleaning water at treatment plants. A research team at Virginia Polytechnic Institute and State University, led by biofluid mechanics engineer Sunghwan "Sunny" Jung, studies the properties of cavitation bubbles. Jung's fluid mechanics lab, supported by the National Science Foundation, is working with food scientists to see how effectively cavitation bubbles can pull away soil, bacteria, or other undesirable particles from the smooth surface of a tomato or the bumpy surface of a cantaloupe. In the future, Jung envisions bubble machines as a common appliance at farmers' markets and maybe even in households. See the fluid lab's website **http://www.beam.vt.edu/sunnyjsh/**, which has other interesting content, such as how dogs drink, or watch a video of cavitation in action: **https://www.youtube.com/watch?v=QuqHy53ffr8.**

BRENDA CARSON/DREAMSTIME.COM

Cavitation bubbles, generated by churning water, can effectively remove dirt and bacteria from fruits and vegetables without adding chemicals.

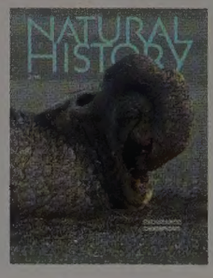
2016 Greenest Cars

The American Council for an Energy-Efficient Economy (ACEEE) has released its nineteenth annual comprehensive environmental ratings for vehicles. Nine out of the twelve greenest cars are electric. According to the ACEEE's press release: "[Mercedes-Benz] Smart ForTwo Electric Drive tops the Greenest List for the third year in a row with an unprecedented Green Score of 63. Toyota's Prius line performs exceedingly well once again, with the new Prius Eco nabbing the 4th spot, while the Prius C and original Prius claim spots #8 and #9. For the first time ever, the Greenest list is completely populated by plug-in and hybrid vehicles; not a single vehicle with only an internal combustion engine appears. This is partly due to the disappearance from the American market of a few of the longstanding entries on the Greenest List, including the Honda Civic Natural Gas. However, the conventional Smart ForTwo and Chevrolet Spark hover just below the Volkswagen Jetta Hybrid." To see the entire list, including the twelve least green, visit **www.greenercars.org.** ACEEE lead vehicle analyst Shruti Vaidyanathan makes a point worth considering before running out to buy: "The 2016 scores are in, and plug-in electric vehicles are outpacing all other vehicle offerings in terms of environmental friendliness. Fortunately, the electricity sector is slated to become cleaner over the life of model year 2016 vehicles, thanks to the Clean Power Plan, and that has bumped up electric vehicles' green scores this year. Nevertheless, it's important to acknowledge that how green your electric vehicle truly is depends on the electricity it uses to charge."

The Mercedes-Benz Smart ForTwo Electric Drive car

Erratum

The image of the elephant seal on the cover of the February issue was taken by Richard James.



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Epigenetic Supremacy

For many creatures, luck in love and longevity depends on social rank. In African cichlids, for example, high-ranking, dominant male fish are the most successful at attracting and mating with females. The factors that influence dominance, however, have been unclear.

Dominance rank in the African cichlid *Astatotilapia burtoni* is not predestined genetically. Non-reproductive subdominant males, originally gray and camouflaged, can suddenly become colorful, reproductively active, and aggressive. Stanford University biologists Kapa Lenkov, Russell D. Fernald, and colleagues examined whether epigenetics—the activation and deactivation of genes over an individual's lifetime—play a role in this profound shift.

In the laboratory, fish were raised "under socially suppressive conditions, meaning that a larger dominant male was in charge," says Fernald. Growing up so they were never dominant, size- and color-matched pairs of males were then placed together in a tank supporting only one territory. Females and other males, visible but inaccessible through a clear barrier, motivated the two males to fight for supremacy. The researchers injected each of the battling males with one of three solutions: a chemical that can methylate, or turn on, genes by adding a molecule; a chemical that can demethylate, or turn off, genes by removing that same molecule; or a control solution. Then they scored male dominance based on color and such behavior as chasing, fighting, and threat displays.

LINDA A. CICERO, STANFORD NEWS SERVICE

A dominant male African cichlid (left), *distinguished by the black stripe on its cheek and eye, threatens a non-dominant male* (right).

The researchers discovered that fish injected with the methylating substance were more likely to become dominant. Conversely, those injected with the demethylating substance were more likely to remain subordinate. In other words, activating certain genes enabled a fish to become dominant, while silencing those genes prevented his ascension. Examination of the subjects' brains indicated that gene methylation prompted a cascade of changes that ultimately increased the production of gonadotropin releasing hormone, which modulates the reproductive system.

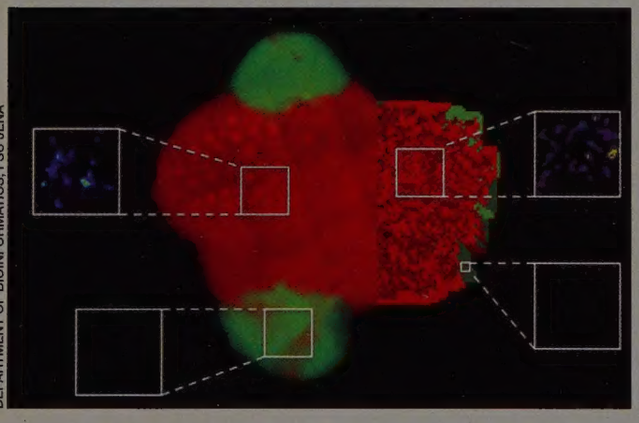
In fish males, "social rank is everything," says Fernald. As scientists are coming to recognize the importance of dominance in all kinds of situations, for humans as well as fish, we now have insight into how it's regulated at the genetic level. (*PLOS ONE*)

—Lesley Evans Ogden

Microbial Moochers

Bacteria, like humans, do not abide freeloaders. In a new study, scientists have revealed that bacteria who do not chip in and share nutrients with their fellow microbial colony members end up as outcasts. These cheating bacteria get excluded from regions in the colony occupied by mutually cooperating bacteria.

Just as human societies opt for divisions of labor, bacteria in colonies often split up the workload. Instead of each bacterium having to metabolically produce the entire suite of nutrients it needs to survive, different microbes will furnish particular vitamins and amino acids, shared for the benefit of their bacterial companions. This cross-feeding strategy makes evolutionary sense; by cooperating with each other as opposed to making an individual effort, bacteria save energy.



S. PANDE/F. KAFTAN, MPI CHEM. ECOL.; S. LANG, DEPARTMENT OF BIOINFORMATICS, FSU JENA

Cooperating bacteria, shown in red, group together and exclude non-cooperative bacteria, shown in green, both in a live experiment (left) *and in computer simulations* (right). *Amino acids—which fuel bacteria—are only available among the cooperative bacteria (see insets).*

Yet scoundrels can arise who seek to exploit the collaborative system. "These opportunistic individuals—cheaters—enjoy the benefits of cooperation without investing resources in it," said the study's lead author Samay Pande, an evolutionary biologist now at the Institute for Integrative Biology in Zürich. Because bacteria reproduce so quickly and in such great numbers, spontaneous mutations resulting in a bacterium that steals from its neighbors pop up repeatedly. How, then, does a cooperating bacterial community avoid breaking down into anarchy?

To find out, Pande and colleagues at the Max Planck Institute for Chemical Ecology and Friedrich Schiller University in Jena, Germany, genetically engineered co-cultures of *Acinetobacter baylyi* and *Escherichia coli* to contain highly cooperative bacteria. They allowed the bacteria to grow either in liquid, which is atypical, or on a more standard flat surface. When floating in the unstructured liquid, cheaters actually grew at faster rates than cooperators, since they had easy access to the latter's secreted nutrients. But in the normal colonial situation where bacteria grow as a layer, the cheaters lost out. The cooperating bacteria clustered together, leaving the freeloaders stuck on the colony's outskirts—a handy method of "cheater control," as Pande put it.

The researchers suspect mutually beneficial cross-feeding is common in natural bacterial communities, especially in "biofilms," the slimy coatings of microbes that can form on teeth and medical implants. Any hints as to how illness-causing bacteria join forces to boost their survival odds could help us eradicate them. (*The ISME Journal*)

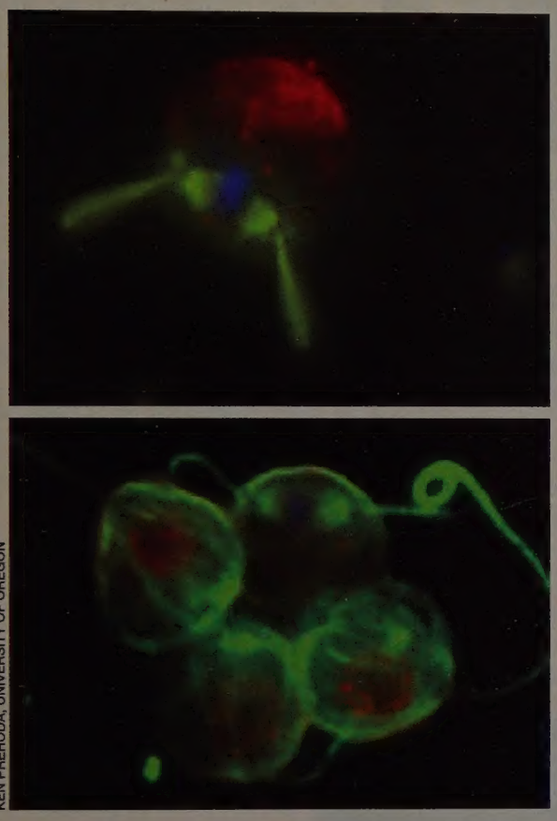
—Adam Hadhazy

Multicellularity

How and when did single-celled organisms give rise to multicellular life forms? This important piece of evolutionary history, enabling cells to specialize, organize into tissues, and form complex animals, had until recently remained obscure.

Biologist Joseph W. Thornton at the University of Chicago and biochemist Kenneth E. Prehoda at the University of Oregon led a team of scientists in reconstructing the evolution of a molecular function key to this transition, which allows animal cells to divide in harmony with neighboring cells. As a cell prepares to divide, a structure called the mitotic spindle forms to split the genetic material between daughter cells. A scaffold known as the guanylate kinase protein interaction domain (GK_{PID}) connects the spindle to anchor proteins in the cell membrane, which aligns the dividing cell with its neighbors. Because GK_{PID} plays a crucial role in coordinating multiple cells within an organism, but resembles another enzyme that serves a very different purpose, the researchers thought that its family tree might provide insight into the evolution of multicellularity.

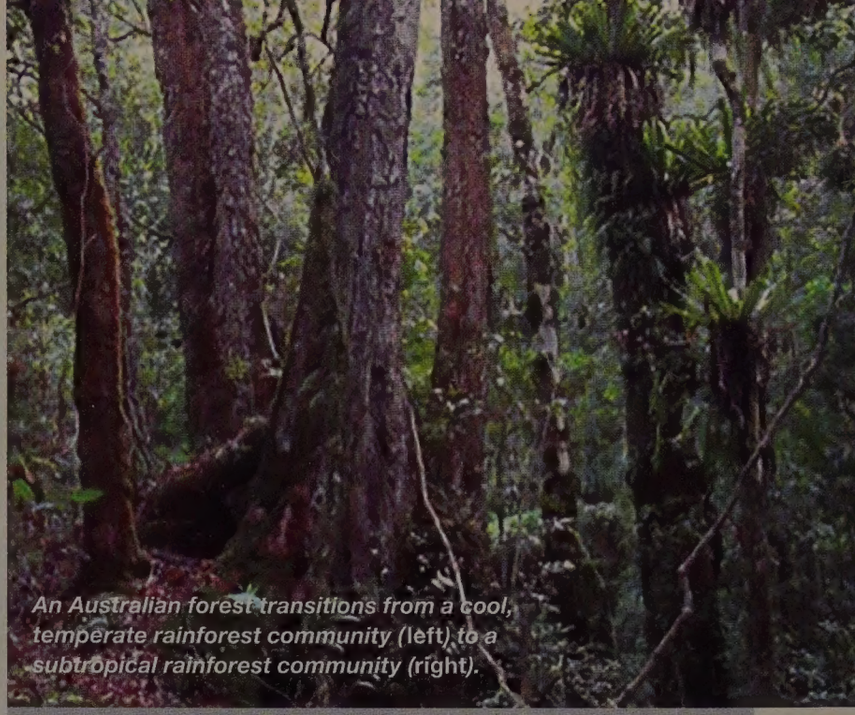
The team first gathered from various databases hundreds of examples of GK_{PID} and other similar proteins in living animals and their closest unicellular relatives, and used them to establish the most likely amino acid sequences for precursors of GK_{PID}. Next, they synthesized the genes to produce those ancient proteins, inserting them in living cells. This permitted the researchers to recreate multiple GK_{PID} precursors along its family tree and pinpoint when its modern role as a scaffolding complex emerged—along with the ancient amino acid sequences that enabled this transformation.



KEN PREHODA, UNIVERSITY OF OREGON

A dividing solitary choanoflagellate with its DNA shown in blue and its flagella and mitotic spindle in green (top), and a small choanoflagellate colony with one of its cells dividing (bottom)

The team found that, roughly 800 million years ago, well before multicellular life emerged, a single mutation could have changed GK_{PID} from enzyme to scaffold. By analyzing the proteins' structural biology, the researchers further discovered that the anchor protein with which GK_{PID} binds nowadays is very similar to the protein with which GK_{PID}'s enzyme ancestor would have reacted. The mutation simply exposed the binding surface on GK_{PID}, eventually allowing it to connect to the fortuitously-shaped spindle-orienting anchor protein which came along much later. (*eLife*) —*Ashley Braun*



An Australian forest transitions from a cool, temperate rainforest community (left) to a subtropical rainforest community (right).

ROBERT KOOYMAN

Competitive Coexistence

Forest diversity has long been attributed to differences in tree traits—how fast they grow, how big their leaves are, how tall they are at maturity—that enable each tree to use resources differently from its neighbors. According to this concept, any unique trait should be advantageous to a tree. But a recent study shows that certain traits enable tree species to outcompete others at different points in a forest's development.

Ecologist Georges Kunstler and colleagues at the National Institute for Scientific and Technological Research for the Environment and Agriculture in France collected data from global plant databases and national forest inventories on three million trees in six major biomes worldwide. They created mathematical models of each tree's growth rate, the size and number of adult trees within fifteen meters of the focal tree, and three traits thought to affect competition: wood density, leaf area to mass ratio, and maximum height. Their goal was to determine how these three traits impact a tree's growth rate, its resistance to competition from others, and its own competitive ability—that is, how well it can suppress the growth of surrounding trees.

The researchers found common patterns across all biomes, from boreal to tropical forests. Trees with higher wood density had slower growth rates, but better resistance to competition from other trees. Low leaf area to mass ratios increased a tree's ability to suppress the growth of others, but had no effect on its own resistance to competition. Trees that ultimately grew taller were slightly less resistant to competition in some biomes, but maximum height had no effect on a tree's competitive ability.

These findings point to a trade-off between growth rate and traits favoring competition. Early in a forest's development, when there are few other trees around, fast-growing trees with low wood density and poor competitive ability can be successful. During later stages of forest development, when competition is high, slower-growing trees with high wood density can dominate. Trees do not gain a competitive advantage simply by being different from their neighbors. Rather, species with diverse traits may coexist if disturbances to nearby forest patches continually alter their developmental stages. (*Nature*) ***—Kati Moore***

The Feminine Touch

Slipper limpets, a type of sea snail, have evolved a reproductive strategy that makes the most of their size at different points in their lifetime. Smaller limpets are males, their tiny stature no barrier to producing energy-cheap sperm. Once larger, the limpets transition to females capable of investing energy into producing and sheltering multiple eggs.

RACHEL COLLIN, STRI

Slipper limpets, shown here in their natural, intertidal habitat, change sex at different times when in physical contact.

The exact size at which this sex change occurs varies between individuals. The presence of other slipper limpets can trigger or delay the change, but the mechanism behind this social influence has been unclear. A new study from biologists Rachel Collin and Allan Carrillo-Baltodano at the Smithsonian Tropical Research Institute in Panama provides the first step in solving this puzzle.

The researchers hypothesized that slipper limpets affect each other either via a waterborne chemical cue, which is a prevalent mode of signaling among aquatic species, or via direct contact. They tested these possibilities in an experiment in which pairs of male limpets (*Crepidula cf. marginalis*), one small and one large, were kept in plastic cups. In some cups the snails were free to touch each other, but in others a mesh screen separated the two, while still allowing water to flow between their compartments.

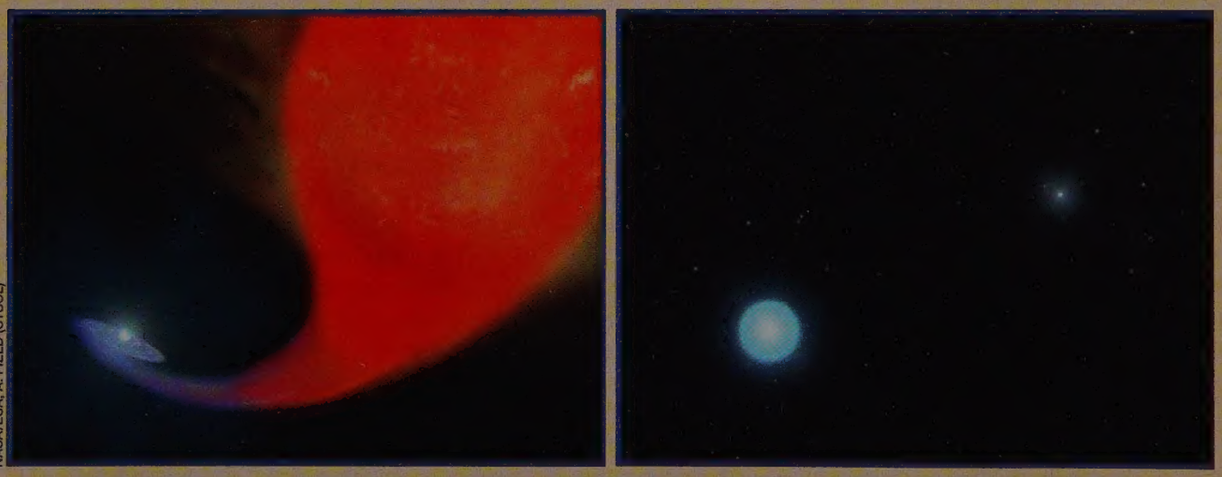
It turned out that when limpets were allowed to touch one another, the larger males grew more quickly and generally changed into females faster than large males in the partitioned cups. The smaller snails in the contact condition also delayed sex change longer than those partitioned. Physical touch between individuals, not chemical messages carried through the water, thus plays an important role in timing the sex transition.

"That was kind of a surprise," says Collin, given that slipper limpets spend most of their lives stationary and filter-feeding. "What we don't know is how that contact is facilitating transition." (*Biological Bulletin*)—*Niki Wilson*

Red Hot and Blue

The exceptionally hot and bright "blue straggler" stars have intrigued researchers since they were first discovered in 1953. They seem to be much younger than the other stars in their surrounding clusters. How did these comparatively youthful blue stragglers come into existence?

To explore this question, astronomers Natalie Gosnell and Robert Mathieu of the University of Wisconsin—Madison and colleagues in the United States and Canada focused on a cluster of stars 5,500 light-years away called NGC 188. At seven gigayears, it is one of the oldest known clusters in our galaxy.



NASA/ESA, A. FIELD (STSCI)

*Blue stragglers begin life as normal, small stars, but pull in matter from an aging companion red giant (*left*). After millions of years, the red giant collapses to a white dwarf, while the blue straggler becomes hotter, brighter, and bluer (*right*).*

Stars typically evolve in predictable ways. We know that our Sun will one day become a red giant, then a planetary nebula, and finally a white dwarf. Stars in a cluster tend to be born, age, and die together, but there are exceptions, like the blue stragglers. Mathieu notes that half of all stars are binaries—they orbit other stars in pairs. Half of all binary couples orbit so close to each other that their mutual gravitational interaction affects their evolutionary process. The researchers wondered whether such interactions might explain how blue stragglers—which appear as single points of intense light—were created.

Observations from the 3.5-meter WIYN telescope at Kitt Peak in Arizona established that over three-quarters of blue stragglers in NGC 188 periodically approach and recede from Earth, indicating that they are part of binary pairs. Hubble Space Telescope observations of ultraviolet light then identified the partner stars as white dwarfs, dying stars that have lost their outer atmosphere and shine intensely in the ultraviolet wavelengths. Mathieu and Gosnell concluded that aging red giants had surrendered hydrogen gas to their nearby companion stars, which in turn became much hotter, brighter, and bluer—in other words, blue stragglers. Over several hundred million years, the red giants collapsed into white dwarfs.

This binary interaction may not be the only source of blue stragglers, Gosnell says. They may also result from stellar collisions, or additional causes that have yet to be recognized. (*Astrophysical Journal*)

—*Harvey Leifert*

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A Chorus of Cranes

The Cranes of North America and the World

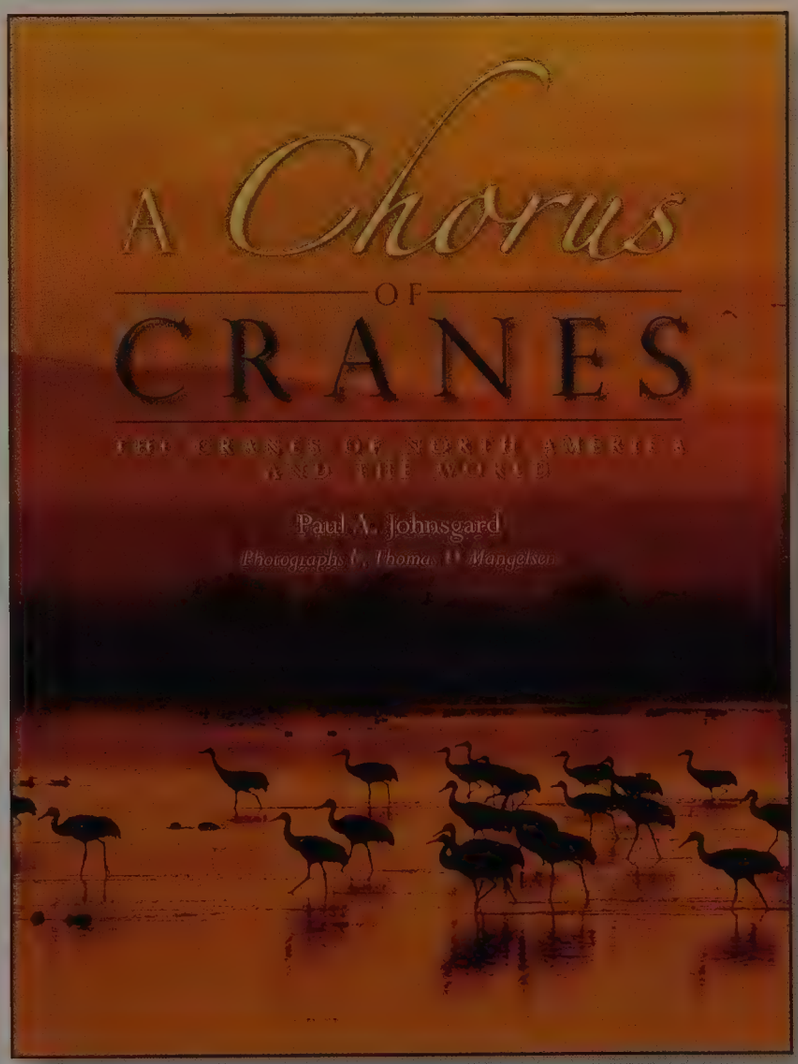
by Paul A. Johnsgard, photographs by Thomas D. Mangelsen

"In this glorious book, Paul Johnsgard and Tom Mangelsen have captured the very essence of these ancient birds—their beauty, grace of movement, and fascinating lives. It is a must for crane lovers, birders, and all who love the natural world."

—Jane Goodall

"Professor Paul Johnsgard is the world's leading synthesizer of our knowledge of birds and the presenter of such varied and complex information to both professional and lay audiences. He has made an enormous contribution to our planet. . . . In his latest book, A Chorus of Cranes, *the splendor of Johnsgard's lyrical style is matched by incomparable images from one of the world's best-known photographers, and fellow Nebraskan, Tom Mangelsen."*

—George Archibald, Co-Founder and Senior Conservationist, International Crane Foundation



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Blue Jays in Touch

The subtleties of jay talk

One early spring morning, a pair of blue jays loitered nearby, making soft calls from the still-bare viburnum bushes. The male approached his mate, and she began to imitate a baby bird, flapping her wings and opening her bill. He placed food in her mouth and she then broke a dry twig off the bush and they both flew to the nest they were beginning to build in a small spruce in the forest. Six days later, while she was pulling rootlets out of the ground for the nest lining, they made soft, fast-repeated squeaky sounds that seemed like whispers. The pair's quiet calls stood in stark contrast to jays' more frequent exclamatory screams that are given both singly and in sets of several in succession and are commonly assumed to be "scolding."

ALL IMAGES JULIA BAYLY

Two blue jays in Fort Kent, Maine

Although I have taken copious notes over the years of when and where blue jays call, I've learned little except that they are much more apt to call when perched than when flying, and the screams are overwhelmingly most likely to be made by birds that are alone. To support that impression, I recorded my sightings associated with screams, observing them in 168 singles, 32 pairs, ten triples, and four foursomes. My observation that blue jays usually call while perched and alone seems odd, since in most species of birds, *crowds* are often conspicuously and sometimes continuously noisy while in flight. Ironically, on rare occasions blue jays do aggregate into groups, and then they are either very noisy or silent, depending on whether they are mostly perched or in flight. Why would they scream when they are alone? Potential insights could only come from observing them in diverse contexts.

On another occasion, while I was pushing my way through a thicket of young alders and pines, I suddenly saw at near eye level a blue jay nest with a parent's tail sticking out at one end. The jay jumped out of the nest, faced me point-blank, and screamed at me. In seconds its mate arrived and also began scolding me. Within a minute six other jays arrived but stayed high in the nearby poplars and maples. They started bobbing their heads and making both rattling and two-note, flute-like calls.

The varied vocalizations of the six new arrivals sounded nothing like those of the pair conveying their agitation. I suspect these newcomers saw that I was not one of the jays' archenemies, an owl or a hawk, that they might have expected when they heard the nesting pair's excited warning screams. Seeing me instead—a human, standing very still and not doing any harm—may have confused them; they dispersed almost as quickly as they had come. The nesting pair stayed. I still didn't move, and then after a few minutes one of them left.

The vocalizations of the pair at the nest with young had been aimed at me, as a warning to a perceived potential predator. The six other jays that had been recruited by this noise had provided no apparent help, except possibly showing the pair that I was not a threat.

Do blue jays routinely come to another's nest if the nest owners sound an alarm? To further test this possibility, I left the nest vicinity and came back a half-hour later to find out if the previous scenario would be repeated. Again, only one of the pair was present, and this time it was not agitated. I was able to reach into the nest and touch the three almost black, featherless young without causing a ruckus. The parent that was present screamed only once or twice, shook its feathers once, and pecked at a branch, but soon appeared much calmer than before. I watched for another ten minutes, and after a while the jay seemed at ease and left. I left as well, planning to return later with the aim of deliberately inducing the pair to scream an alarm, to see if the six others would make a second appearance.

When I next approached, one of

the parents was again on the nest. It flew off a short distance, and this time to provoke it I lifted one of the young out of the nest. This ploy worked: the parent immediately confronted me up close and scolded me even more vigorously than before. Its mate came instantly and gave short, high-pitched, two-note calls plus rolling, liquid-sounding double cries with an undulation in each. I stayed and waited for further developments. The calls became louder, longer, higher-pitched, and more repetitive, and one of the pair finally flew so close to the back of my head that I felt a rush of air from the wing beats. It then showed its anger by hammering limbs and ripping leaves off branches. During the ten minutes that I stayed, the pair's scolding never ceased. Still I heard no responses to the parents' alarm calls from other jays in the woods. I repeated the experiment twice more on subsequent days, and again eleven days after the first encounter. Each time I got the same negative result—no jays came near except the pair. Although this outcome doesn't fit the picture of jays being attracted to others' alarm calls, it does not contradict it. The six that came the first time could have been a group passing through, or if they were local birds, they might have learned what the pair was excited about, considered it a false alarm, and lost interest.

A blue jay fluffing itself out

Some species of jays have "helpers at the nest" (usually offspring from previous clutches) that assist a pair in protecting and rearing young. But none have been reported for blue jays. I now felt confident that there were no helpers defending this nest, and I was also sure the six jays that had been attracted to some of the pair's alarm calls had not come to help. The six jays' investigation of alarm calls was information-gathering behavior: they could learn what had threatened other jays and thus should be watched or avoided. In contrast, the attraction of the mate and possible nest helpers to such calls is mobbing—ganging up on predators to chase them away. I suspect also that the so-called funerals attributed to jays that gather near a dead individual are a variation of, if not the same thing as, one of these responses.

My observations at the blue jay nest convinced me that the jays' screams can act as powerful attractants, but that does not explain why the thousands of other blue jay screams I've heard in the woods have *not* attracted a crowd, nor individual jays. Different meanings are likely attached to different calls, and a large part of the explanation could be variations in the calls—their volume, inflection, repetition frequency, pitch, and other nuances—that were beyond the scope of my methods and scale of investigation.

Blue jays also form another type of aggregation, one that is associated with excitement of a different kind. This excitement occurs typically on the first warming days that herald spring, from late February to late March. Blue jays get together then sometimes in large numbers, and spend hours in palaver. The few of these raucous gatherings that I have witnessed involved from eleven to more than thirty jays and lasted from several hours to most of a day.

On one of those idyllic pre-spring Maine mornings, cold but clear, the sun was bright under a cobalt sky over a deep blanket of snow, and the trees were still bare. No jays were at the feeder at 7:00 A.M., so I was surprised to see six arrive in a group to land in the top branches of a large spruce at the edge of my clearing. There they stayed silent and hidden in the thick branches. Strange, I thought, as I waited a half-hour and neither saw nor heard anything. I walked on the snow crust to the tree, and just as I reached it the birds flew out and scattered into the woods. Soon I heard "jay talk" spread well over a square kilometer, and the talkers included more than the six birds.

Two days later temperatures had risen to 45°F, the warmest day of the year so far. The sun was bright, and blue jays were suddenly in abundance near the cabin. One landed on the tiptop of the same spruce in which the six had perched silently, but this one called. Soon jays were sounding from the forest all around. Groups of two, three, or more began flying into my clearing and perching on the tops of the leafless maple trees. They bobbed up and down in what looked like pushup exercises, accompanying this display with a cacophony of high-pitched, double-note calls so close together that they almost sounded like one. They also made long rattling calls and at least six other distinctly different sounds. By 8:00 A.M. they were gone. But at 11:00 A.M. a group of eleven jays flew in, making a racket. Many of the jays were now

in pairs, performing vigorous pushups, and producing even more kinds of calls. By noon, all had dispersed into the woods, where most of their calls reverted to the usual screams. Since jay palavers of this type occur only in the early spring, a month or so before nesting, they probably function as mate marts, where single birds meet, display, and maybe size each other up and form pairs.

The rare and often dramatic instances of jays coming together—to mob a predator, to rendezvous for mate selection, or to assemble before long-distance travel—are overshadowed by their far more common tendency to be spread through the woods as individuals. What does a jay gain by being solitary in the woods? The answer may be found by determining what it does there.

A few years ago on a still and cold November morning, a blue jay, perched high in a tall sugar maple tree, fluffed itself out, and swiveled its head to look here and there. After some minutes of silence it screamed long high-pitched calls, one after the other, for several minutes on end. Its persistence was unusual, and I wondered if it was alarmed or surprised by something, as per the generally accepted interpretation of screaming.

I peered into the surrounding woods to try to identify some cause of the prolonged screaming. As usual, the screaming bird was hopping around, seeming unconcerned, and randomly looking in various directions. But then I heard a faint scream from the east, perhaps a kilometer away. I couldn't tell whether these calls were random or a response. Yet, the jay near me immediately stopped calling, and I again heard the call of the distant one. My jay called again, and the other replied, sounding nearer this time. Mine then again stayed silent, but the other repeated its calls at intervals, and each time its call became closer. Now the distant jay was coming up the slope and mine flew to the eastern edge of the clearing, precisely to where the other one soon arrived. It landed in the same red maple and made the soft whisper calls often made by couples. Then both flew to my feeder, filled their throat pouches with seeds, and flew off separately, high over the forest and out of my sight. I realized then that a blue jay's home area can be huge. The forest is dense, and it may normally make more sense for a pair, or birds of a group, to forage separately rather than together, as long as they rely on small, scattered food items that must be searched out one by one. The theory seemed to hold for these two, but what about a larger extended family or social group?

Several jays in a snowy dwarf apple tree

On another occasion, I watched a blue jay land about two hundred meters from me, high in a huge red spruce tree. It was silent, hopping through the thickly branched top of the tree as though searching for food. A few minutes later, and without interrupting its exploration of the tangle of branches, it made a few of the usual long, loud, two-note scream calls. Sometimes it abbreviated these calls to make a series of three, varied the pitch, or changed the tempo. All the while it kept hopping, pecking here and there, and foraging, without ceasing its calling.

At a distance of a kilometer or so I heard the faint call of another jay. The one I was watching paid no apparent attention to the sound, not interrupting its investigation of the twigs at its feet. After twenty-five minutes it had traveled only about three hundred meters. It made two or three different scream calls, one call with a higher pitch, and a series of lower, softer calls. I could see far into the leafless maple woods, and there was not another jay in sight. After a half-hour the solitary jay flew off silently to the northeast, from where I had heard no calling. On the face of it, it seemed to have "talked to itself" the whole time. But had it been heard and listened to by others?

The actions of these two blue jays might not have been interesting except for the contrast with what happened two hours later in the same woods. I heard the call of a red-tailed hawk and saw it sail low through a silhouette of trees, quickly out of my sight. (I was glad to see it, to confirm that it really was a red-tailed hawk, because local jays mimic to appar-

ent perfection the calls of both the red-tailed and the very different-sounding broad-winged hawks). Almost immediately a blue jay started calling, then two, then three chimed in. Within a minute there were more jays and I could no longer distinguish individuals. Then there was a melee of calls, and yet another jay flew over me from the direction of the commotion. These were indeed

jay screams, but they had a different tenor from the lone foraging birds' recent calls that might have been heard but were usually not answered. Fifteen minutes later the jays became silent. Many jays must have been in the nearby woods before the hawk came, and likely afterward, and they would have heard the first jay, the one I watched, vocalizing as it foraged near me.

From then into early April, I heard jays scream many times each day. Groups of two or three flew here and there in no specific direction, and there was hardly a moment when I did not hear a jay calling from somewhere in the woods. But after early April, the woods were silent of jays. I saw none, as if the woods had been swept clear of them. Only a pair remained by my cabin.

My observations are consistent with the inference that although blue jays are solitary in some of their food gathering in the northeastern forests, perhaps it's only because they often have to be when food is dispersed. Yet, they broadcast specific loud screams into the otherwise silent woods, which neither attract others nor warn them, but may serve as distant markers for the presence of each member of a social group.

Scattered blue jays do not look like a group of associates while they are foraging separately on widely distributed food in a forest. On the other hand, traveling to new foraging areas and to clumped food, such as the locally and seasonally available acorns and beechnuts, requires long-range movements, which are made by the group all together. Having to move seasonally as well as geographically, jays somehow manage an apparent flock organization without staying in a flock continuously. They keep in touch vocally when separated, and can then assemble and move together.

I have now arrived at what I think is the most reasonable hypothesis for these long, loud calls that act neither as warning nor recruitment signals. What can be the advantage of such seemingly costly behavior as "talking to themselves," which might attract the attention of predators? The scream of the blue jay, I now suspect, is simply saying, "Here I am. How are you?" Listeners can then feel reassured that they are not alone in the area, and can either ignore it or reply, "Here I am, too." Depending on inflection, length, repetition, pitch, and context, it likely has subsidiary meanings such as "All okay," "I'm excited," or "This is scary, come check it out." Very different loud sounds uttered only at the pre-spring rendezvous may mean "Look at me: I'm available." Soft whispers in the presence of a mate may mean "I like you. I want to stay with you."

In any relationship where the individuals are separated, either by distance or by such visual barriers as a thick forest, "giving a shout" now and then—whether or not there is an immediate answer, so long as it is heard by the intended recipient—can be important without conveying a specific message. After realizing the likely nonspecific but nevertheless meaningful social nature of the blue jay scream, I think I am now less hesitant to call, e-mail, or send a letter or a "hello" even when, as almost always, I have nothing "important" to say. I have learned more from the blue jays by inferring something from them than by attributing a message to them.

Excerpted from *One Wild Bird at a Time* by Bernd Heinrich. To be published in April 2016 by Houghton Mifflin Harcourt. Copyright © 2016 by Bernd Heinrich. Reprinted by permission.

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The Life of a Lake

In the Late Cretaceous period, which ended 65 million years ago, the Arabian land mass began to move northward away from Africa, splitting the earth with a hairline fracture that ran from Africa to Turkey, eventually opening up the Red Sea, and passing between today's Israel and Jordan from the Gulf of Eilat north through the Aravah Valley and the Dead Sea, continuing up the Jordan Valley, through the Sea of Galilee and the Huleh Valley. In its early stages, this part of the tear in Earth's surface was a shallow depression that was periodically filled in. But gradually, with the continued slow movement north of the Arabian block—about sixty miles in total by the present—a modest trench was outlined. That trench became substantial enough to hold a lake only around three million years ago, when the northward movement of the Arabian Peninsula shifted to the east, pulling open the valley. The valley, though not as deep as it would become, had essentially acquired its present shape.

The creation of the Great Rift Valley, or Syrian–African Rift, a valley stretching 3,700 miles from eastern Africa's Zambezi Valley to the Taurus Mountains of Turkey, proceeded slowly. The Great Rift, which looks in satellite photographs like nothing more than a slight scar, is not one continuous valley, but rather a chain of basins loosely strung together and of varying depths and ages. When it initially opened, it was as though a wedge were being driven slowly up the plain, the force of it opening one gap after another, some of the earlier ones getting filled in as new ones came into existence. The long, narrow fissure cuts through what are now mountains, crosses stretches of land that have become deserts, and passes through the open sea. Its deepest inland section contains the Dead Sea, and reveals the stele-like engraved evidence of the processes that have marked the maturation of our planet in the last several million years.

The east and west sides of the Dead Sea valley differ surprisingly given the fact that they are only six to twelve miles apart. The exposures—that is, the visible rock formations—are much older on the east. Igneous rock is covered with the 400-million-year-old red Nubian sandstone that has made the mountains of Moab famous for their beauty. The western cliffs are not as high as the eastern ones, and their brown exposures of chalk, limestone, and dolomite date back only to the initial opening of the Rift. The visual discrepancy is unavoidable, and so impressive

Recent view of the Dead Sea shore, showing vast recession

WIKIMEDIA COMMONS/DAVID SHANKBONE

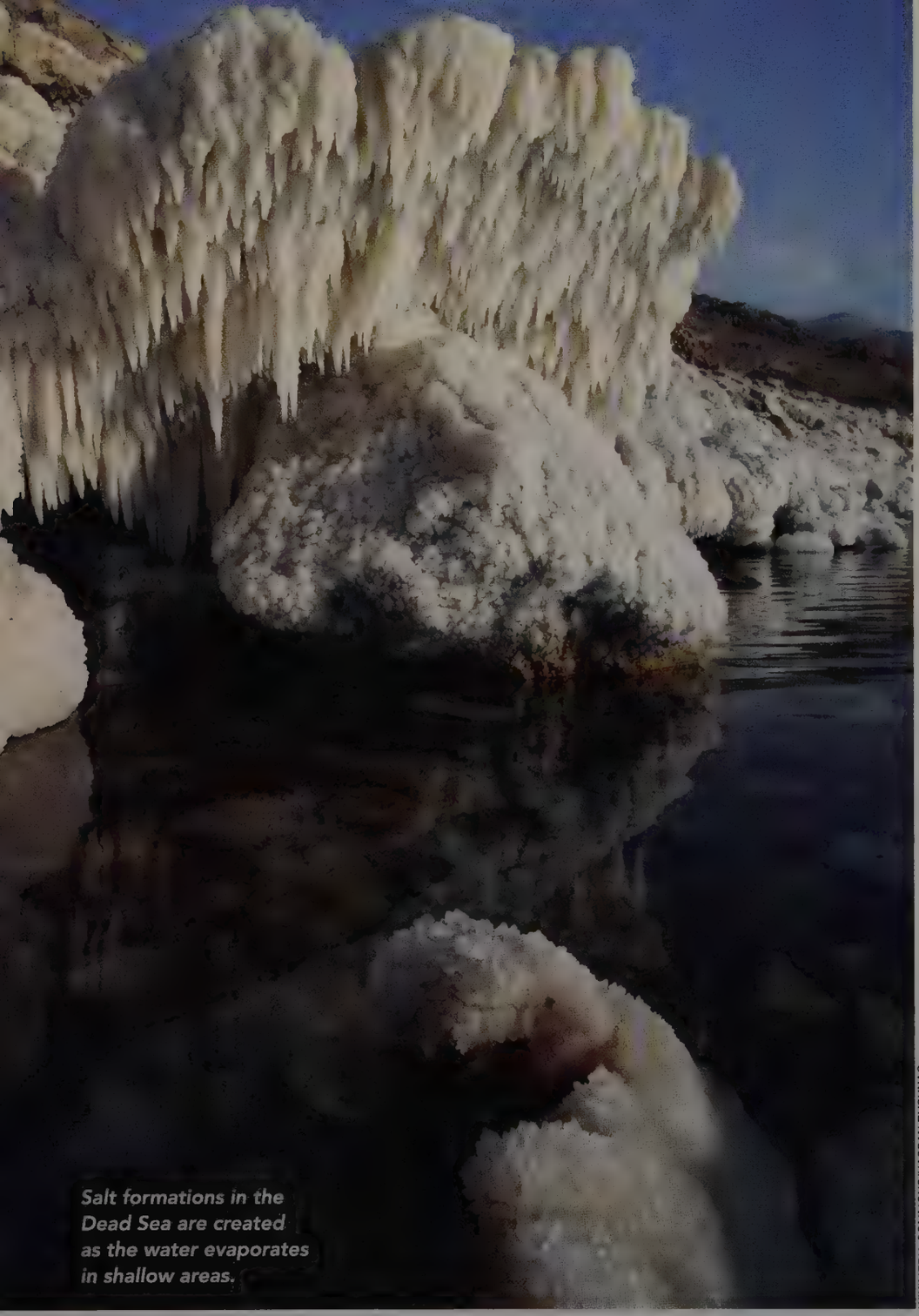
Geological events have made the Dead Sea geographically and chemically unique.

By Barbara Kreiger

that one of the first questions a traveler is likely to ask is how it came to be. The answer lies in the very forces that created the Rift Valley; if we look on the west side for a match of the reddish sandstone mountains of the east, we do find it—but not directly across the lake. Rather, the mate is to be found sixty miles south, the distance serving as evidence of the movement of the Arabian Peninsula, movement that continues at a slow but inexorable pace.

The last important movement in the Rift Valley took place in the geological period immediately preceding ours, during which time the valley continued to sink. Familiarly called the Great Ice Age, the Pleistocene was an epoch of glacial periods and interglacial thaws alternating over a large part of the earth. Every time the ice melted, perhaps four times in all, soil would reappear on the cold planet, bringing with it vegetation in these interim periods, each of which lasted around 200,000 years. Areas south of where the ice sheets spread reveal traces of lakes where today there are none, as well as evidence that certain extant lakes were once much larger. All of this suggests that those regions experienced periods of intense precipitation and a low rate of evaporation; it is believed that these pluvials coincided with the ice ages of colder regions, and that the lakes shrank during the interglacial, when the climate turned dry. This cycle of the expansion and contraction of lakes in warm regions characterized the Pleistocene and is important to the evolution of the lakes in the valley.

Before any lake existed there, another process was taking place that would have the most pronounced effect on the composition of the Dead Sea valley. As the rift opened around three million years ago, the Mediterranean washed inland down to the Jordan Valley in a bay-like extension. The bay's story is one of alternating penetration and recession that lasted hundreds of thousands of years. The climate was dry and the rate of evaporation high, ideal conditions for the precipitation of salt, which sank to the lowest point in the basin, the part that would one day be occupied by the Dead Sea. Eventually, probably around two million years ago, the connection with the sea came to an end, perhaps because the valley's further subsidence left high land as interference. From then on, both the level and salinity of whatever lake occupied the closed depression would be determined by the relationship between inflow and evaporation. Though the link to the ocean was a thing of the past, a permanent mark on the Dead Sea valley remained—a bed of salt that drilling has



Salt formations in the Dead Sea are created as the water evaporates in shallow areas.

WIKIMEDIA COMMONS/HASSAN BUSHNAQ

so far established to be almost two miles thick, and which could be twice that.

The story of this salt deposit continued as the dry period during which it was accumulated turned humid. When flooding began, enormous quantities of rock and sand were washed down into the basin, where they settled on the salt bed. As the floods continued, the new layer—at least a mile deep—grew thicker and heavier, until the rock salt was softened by the great pressure. Squeezed against the sides of the basin, it sought an escape through faults and began to seep upwards, eventually floating all the way to the surface of the lake under which it had lain. Geologists explain the effect in terms of a bucket of mud into which a large, flat stone is placed, forcing the mud to creep up the sides of the pail. In this case, the "mud" became on one side the Lisan Peninsula, whose cliffs rise as much as 150 feet, and on the other side Mt. Sedom, later thrust up to 600 feet high. The mountain is composed of a core of solid rock salt, and its nearly vertical stratifications—very different from the horizontal ones found in most mountains—attest to this origin of intense pressure.

A number of lakes have occupied the deepest section of the Great Rift, but little is known of the very early ones. Investigators believe that these bodies of water ran the whole spectrum from fresh to hyper-saline, and they think that in the not-too-distant past, around 100,000 years ago, the lake that was formed by a return to a humid period was a fresh-water one. Whether it was a single lake or a system of smaller ones is not clear, but this so-called Samra extended the length of the Jordan Valley. When the rains that created it stopped, it became increasingly saline and was converted, by virtue of this change in composition, into the important Lisan Lake, the immediate precursor of the Dead Sea. The rains returned, and the young Lisan grew enormously, stretching far beyond the territory that would be covered by its successor. Extending at its maximum from beyond Tiberias in the north to Hatseva in the south (further than the southern limit of the Dead Sea), the Lisan was six times as long as the Dead Sea and, though it was probably not as deep, had a volume of water four to five times as great.

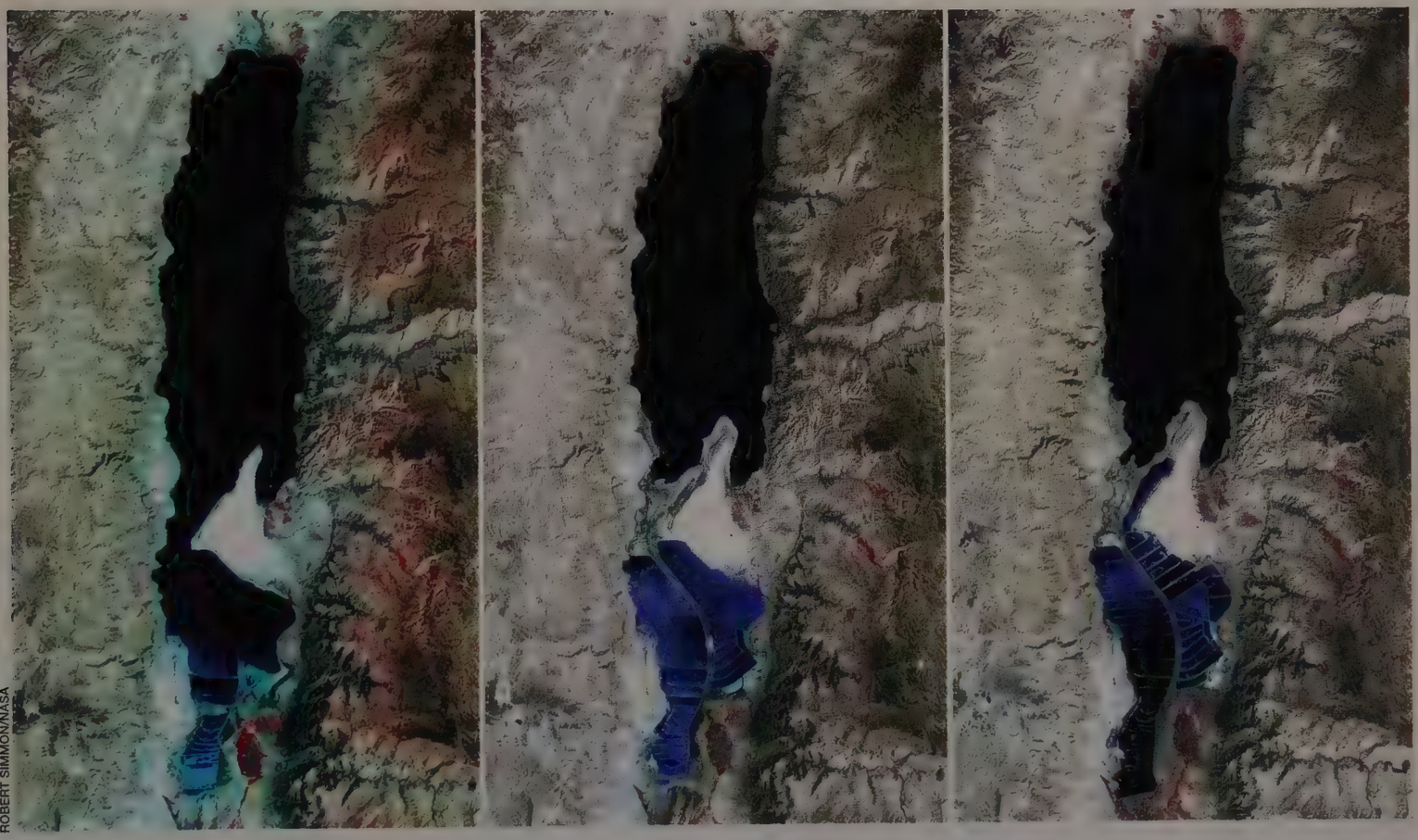
During the first part of the lake's existence, torrents of water raged down the mountains, joining the rains that poured into it. The low rate of evaporation was nowhere equal to the task of countering the inflow, and the lake rose to a level 660 feet higher than the Dead Sea is today. The evidence of this may be found in the cliffs. In the long ago post-pluvial summers, when evaporation was very high, aragonite, a white mineral, precipitated to the lake's bottom in a thin layer. In the winters, floods washed down clay and small fragments of stones that also settled to the bottom in a thin, brownish layer. After thousands of years of seasonal cycles that must have been much more extreme than today's, the bottom of the lake had come to consist of a thick bed of this thinly laminated marl, its white layers clearly distinguishable from the brown. As the lake shrank, its floor was exposed, and

the laminated deposits left by its recession have been found in the cliffs as high up as 660 feet. Spread from the Sea of Galilee in the north to Hatseva in the south in the shape of flat-topped hills as high as one hundred feet or more, this so-called Lisan Formation may be the single most distinguishing feature of the Jordan Valley.

The Lisan Lake reached this high level about 23,000 years ago, after which an arid period caused it to plunge to well beneath the current level of the Dead Sea. Although some of the lowering was caused by subsidence rather than actual shrinkage, dramatic changes in the climate had unmistakably taken place. The reduction in inflow and escalation of the evaporation rate were such that the mammoth prehistoric phenomenon came close to disappearing about 18,000 years ago.

During this severe recession of the Lisan, its two major basins were exposed. The northern Beit Shean basin today contains the Sea of Galilee, and from the end of the Lisan period ceased to be connected with the evolution of the Dead Sea. The other basin would come to hold the Dead Sea, a lake differing greatly both in size and composition from its predecessor. As the composition of the Lisan distinguished it from its freshwater parent, so the slow development of the Dead Sea's singular composition would mark another turning of the generations. The approximate age of 12,000 years that has been assigned to the Dead Sea roughly coincides with these two foremost factors—the confinement of the post-Lisan Lake to a vastly smaller area, and the markedly different composition once that basin refilled. In addition, its great depth (some one thousand feet) may be attributed to further tearing of the valley's floor, a process that filled those interim millennia.

Like the Lisan Lake, the Dead Sea has been prone to quick and severe level changes. On both the east and west sides of the lake, one can see the horizontal lines that mark prehistoric shorelines. Although its level varied considerably over the years, the lake was in a relative state of equilibrium, because the huge water loss it experienced through evaporation was compensated for by inflow from various sources. The primary source, contributing sixty percent of all the replacement water, was, until the 1960s, the Jordan River. The largest contributor now—taking into account annual variations—is winter flooding.



ROBERT SIMMON/NASA

False-color images of the Dead Sea, captured by Landsat satellites in 1972 (left), 1989 (middle), and 2011 (right). Blue and dark blue show deep waters, brighter blues indicate shallow waters or salt ponds (in the south), pale pink and sand-colored regions are barren desert landscapes, green indicates sparsely vegetated lands, and denser vegetation appears bright red. Near the center is the Lisan Peninsula, which forms a land bridge through the Dead Sea.

The lake lies in a desert that occupies the eastern flank of the Judean Mountains, which run north and south through the central portion of Israel. The Judean Desert is not part of the belt that includes the Sahara, Sinai, Negev,

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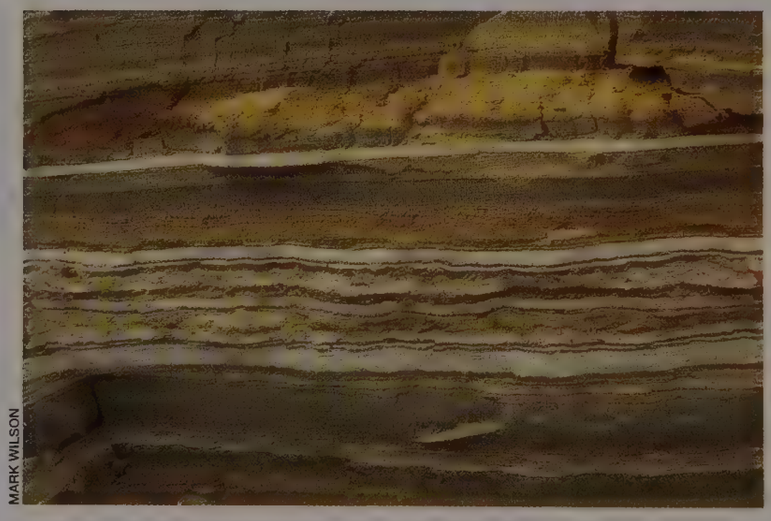
Mount Sodom in the Dead Sea Rift Valley was formed—and is still forming—as subsurface salt (sodium chloride) is forced above ground by massive overpressure of more dense sands and gravels.

and Arabian deserts. Rather, it is a rainshadow desert; its situation on the lee side of the mountains, where it is shielded from most of the moisture-bearing winds that come off the Mediterranean, is responsible for its aridity. Jerusalem, some three thousand feet above sea level, receives an average of twenty-five inches of precipitation annually, but when the rain clouds descend into the valley, they are warmed and in effect dehydrated; thus the northern end of the Dead Sea receives only four inches. Once the clouds reform and scale the Moab Mountains, they are cooled, showering the eastern range as they had showered the west. Only the Dead Sea basin itself remains dry.

The uniqueness of the Dead Sea's more than thirty percent salt content has provoked the interest of investigators for centuries. The 1950s and '60s, however, were the decades of revelation. Not only did the sophistication of the tools catch up with that of the investigators, but the simple development of the Dead Sea valley—construction of roads, for example—made the lake more accessible. In 1959, the American/Israeli team of marine geologist Kenneth O. Emery of the Woods Hole Oceanographic Institution and David Neev at the Geological Survey of Israel began a systematic study of the physical, chemical, and geological aspects of the Dead Sea. The study, which they published in 1967, quickly became a cornerstone of modern Dead Sea scientific exploration.

At around the time that Neev and Emery were working, test borings at Mt. Sedom were made in connection with oil exploration. The deep salt that the drills penetrated was analyzed and found to contain ordinary pollen that had been carried by prehistoric wind and had settled on and been preserved in the salt mound. When the Mt. Sedom pollen was dated at three million years old, Neev and Emery concluded that the salts of the Dead Sea must also be that old. Dating the salts was the single most important event in verifying their source. As mentioned earlier, the Mediterranean had at one time washed into the rift, depositing, after hundreds of thousands of years, a salt bed more than two miles thick. If the source of the Dead Sea's salts were the ocean, one would expect the lake's mineral content to correspond with that of the ocean, yet it does not. The ocean contains primarily sodium chloride; the Dead Sea has a very large quantity of magnesium and calcium chloride. The discrepancy results partly from the different precipitation tendencies of minerals. As water becomes saturated, sodium chloride falls out of solution much before magnesium chloride, which is among the last compounds to crystallize. So even though the Dead Sea itself is high in magnesium, examination of its sediment reveals, as expected, a very high sodium content.



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A salt bed showing layers of silt and salt, with salt layers only at the top of the sequence. Older salt deposits were dissolved and washed away by fresh groundwater coming from alluvial fans.

As the Jordan River flowed to the Dead Sea, it washed over the Lisan marl that coated most of its course and brought down additional salts. Those salts were not the Jordan's own, but those of an earlier era reactivated by the washing action of the river. Recycled, as it is, the salt of the Dead Sea is much older than the lake itself, dating back to the penetration of the valley by the open sea three million years ago.

When the long, flat-bottomed dish that is the Dead Sea depression cracked several million years ago, its two basins

were created, evolving from that point on as independent units. Any subsequent movement in the valley did not affect them equally, and the difference in their respective depths became more and more pronounced. The last major movement left between them a raised rim (which eventually cracked) that separated the two basins so effectively that the lake was probably confined to its northern basin until well into historical times.

So great was the difference in the depths of the two basins that it seems at first improbable: the northern basin was as much as a thousand feet deep, while the southern averaged around fifteen. Because of its shallowness, the southern basin more immediately responded to atmospheric conditions than did the northern one. It was more prone to temperature changes and experienced an even greater rate of evaporation. The discovery of this difference by Neev and Emery turned out to be a key to understanding the currents. The southern basin's greater density had created, in effect, a slope; magnet-like, it pulled the water from the north, producing a southerly current and sending back a northerly stream in return. Through isotopic analysis, modern investigators have been able to "see" the different compositions of the currents.

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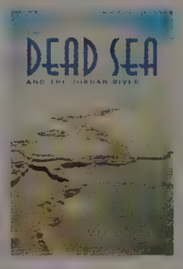
From early in the twentieth century, individuals with practical interest in the nature of the Dead Sea had also noticed that the lake's salinity was not constant at various depths and that in fact the sea appeared to be quite sharply stratified. Neev and Emery noted that the northern basin of the Dead Sea consisted of distinct layers of water that differed sharply in temperature, density, and salinity. There were two major layers, sandwiching a middle one. The so-called upper water mass extended from the surface down 120 feet, and the lower mass down to the bottom. So extreme was their difference that simultaneous evolution was thought to be out of the question. The lower layer might be characterized as a fossil water body—one that has been completely sealed off for so long that it has ceased to interact in any way with the atmosphere. The upper layer must have accumulated relatively quickly for this to have happened. The question was what sequence of events brought about this accumulation.

In order to identify such events, the upper water mass had first to be dated. Neev and Emery determined an approximate age of 1,500 years, and looked to the end of the Byzantine period for an explanation. Other researchers performed a calculation based on the age of radioactive isotopes and arrived at an age of only about three hundred years. Still others looked for a climatic context. The seventeenth century was fairly wet in this region, and the eighteenth comparatively dry. Beginning around 1820, another wet period began raising the level of the lake for the next century. Some researchers, their argument bolstered by specific gravity measurements, believe that the upper water mass could only have been as old as that recent accumulation, namely, 150 years.

The Dead Sea itself can no longer divulge the answer to this question. Since 1975, it had been clear that the surface layer of the lake was becoming increasingly saline, probably because of the tapping of the Jordan River system. By 1976, the difference between the layers was negligible, and by mid-1978, the upper layer was actually saltier than the lower. Stratification, however, was maintained because of the temperature difference between them. That winter, with the cooling of the upper water mass, a dramatic event took place: the lake "overturned," its water becoming more or less homogenized for the first time in at least one hundred and fifty years.



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SAMAR M. SALMA

Barbara Kreiger is Creative Writing Concentration Chair and adjunct associate professor in the Master of Arts in Liberal Studies program at Dartmouth College. Her other publications include *Divine Expectations: An American Woman in Nineteenth Century Palestine.*

Evidence of Early Takeoff

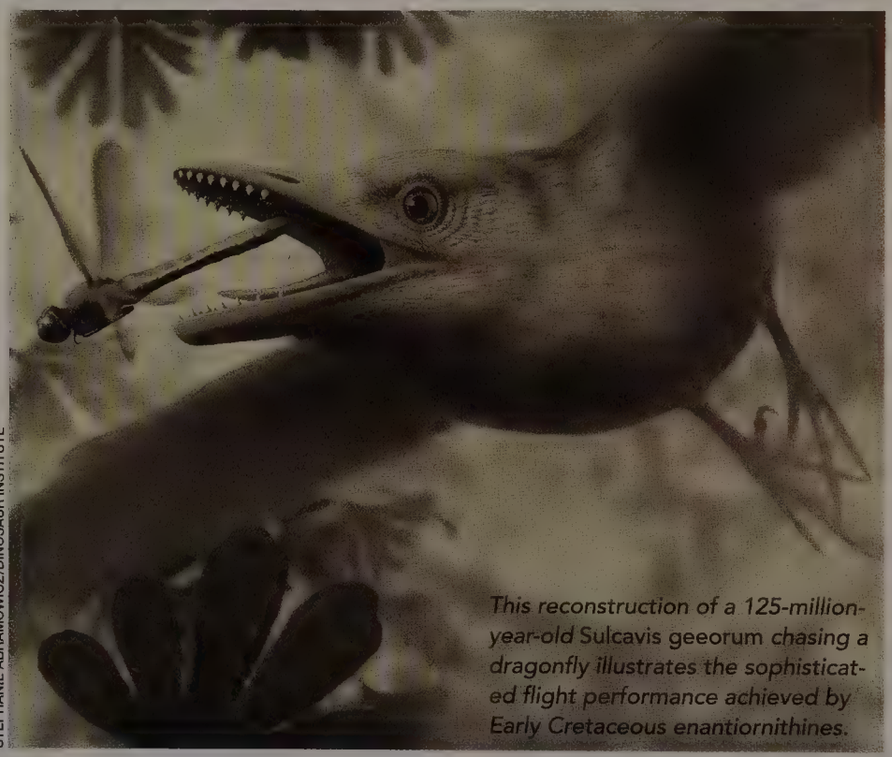
The fossilized wing of a 125-million-year-old bird has the necessary structure for flight.

By Luis M. Chiappe

Feathers, with their insulating properties, can regulate body temperature, and colorful plumage can be a sexual attractant, but flight takes strength and coordination. In modern birds, networks of smooth muscles attached by elastic tendons to the outer walls of feather follicles control the coordinated movement of groups of feathers. In the wing, a well-developed array of such tendons and feather muscles—erectors, depressors, retractors, and rotators—together with other ligaments provide structural strength and allow the range of motion crucial for controlling lift and maneuverability during flight. For instance, the contraction of rotators results in a counter-clockwise movement of the flight feathers, which counteracts the passive rotation of the feathers caused by aerodynamic stresses that impact the wing's ability to generate lift.

The evolution of the modern network of smooth muscles, elastic tendons, and ligaments involved in the function of the wing's flight feathers was a paramount event in the fine-tuning of aerodynamic capabilities in birds. By allowing these feathers to be repositioned in tandem, this sophisticated dermal system helped the wing to maneuver as a single functional unit and to cope with the strenuous aerodynamic stresses of flapping flight.

The first known dinosaur species with feathers was found in 1861 in a limestone quarry in Solnhofen, Germany. From well-preserved remains, this species was identified as a small theropod, about 150 million years old, and was given the taxonomic name *Archaeopteryx lithographica* (lithography being one of the uses of Solnhofen limestone). *Archaeopteryx* has long been accepted as the earliest known bird, and today the evidence indicating that birds are evolutionarily nested within theropod dinosaurs is overwhelming. The importance of the find is undisputed; interpretations of the bird's place in the evolution of avian flight, however, remain contentious.

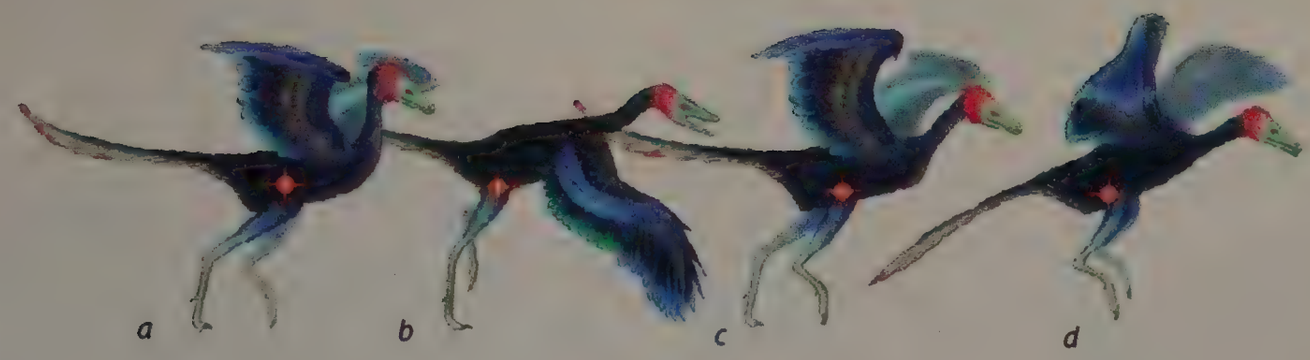


STEPHANIE ABRAMOWICZ/DINOSAUR INSTITUTE

This reconstruction of a 125-million-year-old Sulcavis geeorum *chasing a dragonfly illustrates the sophisticated flight performance achieved by Early Cretaceous enantiornithines.*

Since the discovery in Solnhofen of *Archaeopteryx*, numerous fossils of Mesozoic bird species have been found around the world, revealing detailed evidence of plumage and other soft-tissue structures. The soft-tissue structures essential for flight, however, have remained largely unknown, specifically the epidermal and dermal anatomy of a wing's patagia—the skin or membrane in which feathers are inserted. But a recent discovery in Las Hoyas, Spain, of a fossilized wing of an Early Cretaceous bird, a member of the then-prevalent Enantiornithes, provides evidence of the oldest known occurrence of connective tissue associated with bird flight. The presence of an essentially modern connective arrangement in the wing of an enantiornithine suggests that these primitive birds were competent fliers.

The Las Hoyas limestones, near the city of Cuenca, have been excavated every summer for the last twenty-five years by crews from the Universidad Autónoma de Madrid. Thousands of fossils, many of them spectacular, have been unearthed, but only a handful of them have been birds. As with the limestone quarries in Solnhofen, the Las Hoyas site was once submerged and had conditions ideally suited for the preservation of soft tissue from both aquatic and terrestrial flora and fauna. The new fossil was collected two-and-a-half years ago during one of these summer expeditions and brought to my attention by my colleagues in Madrid. Guillermo Navalón, the first author of the paper published about this finding in the 6 October 2015 issue of *Scientific Reports*, is a doctoral candidate at the University of Bristol



TOM MOORE

A primitive bird, or a theropod dinosaur, could have increased its thrust by flapping its wings (a, b). The enhanced thrust would have boosted its running speed and, at the same time, increased its lift, the upward force created by air moving across its wings (c). As lift increased, the force between the bird's hind limbs and the ground would have decreased until it reached zero and the bird took off (d). The bird's center of gravity (red crosshairs) would not have moved up or down until the bird left the ground, because the vertical components of all the forces would have remained in equilibrium.

in the United Kingdom. For three months last year, he and I studied the fossil at the Natural History Museum of Los Angeles County.

To appreciate the significance of this fossil, which is currently labeled MCCMLH31444 while awaiting a taxonomic name, some understanding of avian anatomy and of aerodynamics is required. The arrangement and microstructure of the plait-like muscle fibers observed in MCCMLH31444 suggest that they were capable of buffering against multidirectional forces, such as the ones exerted on modern birds' flight feathers. This suggests that the wing of MCCMLH31444, and most likely that of other flighted enantiornithines, formed an airfoil capable of enduring important aerodynamic stresses. The modern anatomy and arrangement of the soft tissues preserved in the wing of MCCMLH31444 implies that Early Cretaceous enantiornithines had already developed forelimbs anatomically well-adapted for flight, losing most of the primitive grasping functions attributed to the dinosaurian forerunners of birds.

Although still showing a suite of primitive skeletal traits, even the earliest enantiornithines (such as the 131-million-year-old finch-sized *Protopteryx fengningensis*) had already developed a flight apparatus of modern proportion, including a keeled breast bone for the attachment of two major flight muscles and an advanced shoulder girdle channeling the tendons of these flight muscles, all of which suggest active flapping and a wing stroke similar to that of present-day birds. Integumentary similarities with modern birds, such as wings with identical feather arrangement and a well-developed alula (a tuft of small feathers attached to the thumb), also point to the same functional conclusions. The preservation of three important skin folds—propatagium, alular patagium, and postpatagium—together with the above-mentioned dermal system in the wing of MCCMLH31444 lends strong support to the notion that these primitive avians had achieved aerodynamic competence comparable to those of many modern birds. Still unanswered, however, is how they first achieved takeoff.

As I discussed in the single-topic issue on dinosaurs taking flight [*Natural History,* 5/2005], since the late 1800s, two antagonistic theories have sought to explain the onset of avian flight. Some investigators have argued that birds became airborne "from the trees down," as their theropod predecessors mastered tree-climbing, then parachuting and gliding, and finally powered flight. Others have countered that small land-dwelling dinosaurs learned to fly without ever developing arboreal habits: no trees were needed.

The fossil record makes it clear that theropod dinosaurs lived a terrestrial existence. Their long legs and short toes were well-suited for running. Fossils of bipedal, birdlike dinosaurs such as the parrotheaded oviraptorids, the lightly-built troodontids, and the sickle-toed dromaeosaurids have been discovered in positions that indicate they were brooding their eggs, but always in nests on the ground. Some of them have been unearthed in dormant poses, indicating they also rested on the ground.

Furthermore, these animals evolved the skeletal framework necessary for flapping their feathered forelimbs—the functional precursors of powered flight. Fossils spanning the evolutionary transition from theropod to bird also demonstrate how the wings of these animals became larger as their bodies became smaller. Aerodynamic studies have documented how, by flapping their wings, the animals could have boosted their running speed. Taken together, the evidence suggests that flight could have evolved as a by-product of wing-assisted running in animals that were becoming lighter even as their wings were becoming bigger.

Theories about the origin of flight will continue to be conjectural. Yet aerodynamics, the potential for locomotion, and the documented habits of birds' predecessors all make the ground-up hypothesis the less conflicted of the two options. At least now we have fossil evidence that avian ancestors mastered flight some 125 million years ago.

Luis M. Chiappe is Vice President of Research and Collections, and Director of the Dinosaur Institute, at the Natural History Museum of Los Angeles County.

Feathers

Blue-and-yellow macaw, Ara ararauna. A detail of the resilient shaft of the macaw's primary feathers.

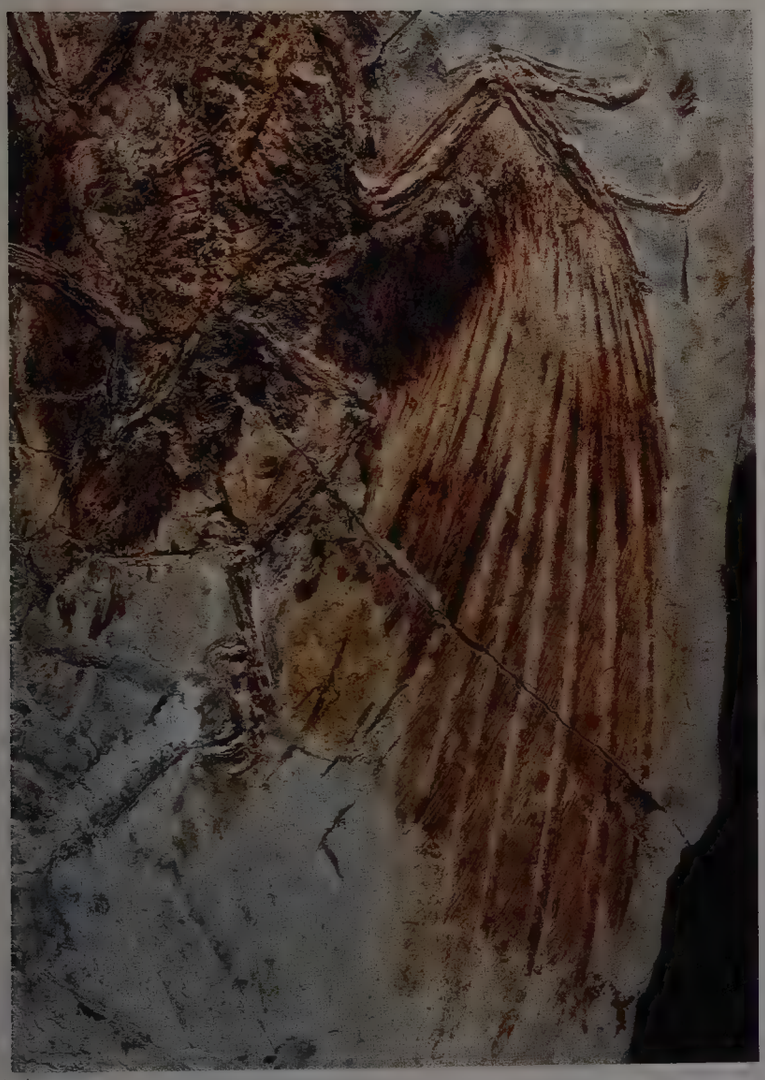
Displays of Brilliant Plumage

BY ROBERT CLARK

The ways in which feathers have evolved and manifested themselves over time is riveting; over millions of years the scales of a dinosaur deviated and began to grow upward in spines that covered the body of birds. Through many generations, these spines spread, evolving specific purposes for the regions on the body on which they grew; eventually these spinal structures were imbued with extra-

Archaeopteryx lithographica

A single distal secondary feather from a deposit of fossils discovered in Solnhofen Community Quarry in Germany, in 1861. For a long time this feather from the late Jurassic period—more than 150 million years ago—was the oldest known example of a feather in the fossil record.



Confuciusornis

This Aves variation, discovered in the Liaoning province of China, shows a member of Confuciusornithiformes, a group of bird predecessors all identified by talons evident on their forelimbs. Named after the Chinese philosopher Confucius, these animals are the oldest known birds to have beaks.

Southern giant petrel, Macronectes giganteus
To survive, these arctic birds have developed physiological and biological adaptations, including nasal passageways that filter out the salt from the air and wax ester–filled glands that the birds use to spit on attackers. A dense overlay of feathers gather together to form a high-aspect-ratio wing type, designed to fly with minimal effort in all conditions, allowing the birds to glide for much of their flight as they soar throughout their enormous roaming area.

vagant colors and features. Feathers evolved for all kinds of purposes: flight, insulation, sexual attraction, camouflage. In order to chronicle the amazing evolution of plumage, I have pored over thousands of feathers and photographed hundreds—from fossilized feathers dating back millions of years to the spectacular feathers of today's birds-of-paradise. If form follows function, then, when it comes to feathers, beauty follows form.

Golden-headed quetzal, Pharomachrus auriceps
The vibrant feathers of the quetzal have been sought after for hundreds of years. The Aztec and Maya of Central America once adorned their crowns with the green plumes of the local varietal, the resplendent quetzal, Pharomachrus mocinno. *This particular feather comes from a species found mainly in the upland jungles of Bolivia, Colombia, Ecuador, Peru, and Venezuela. They are distinct from the other quetzal species in that they have orange and gold head coloration and black underfeathers.*

Golden-breasted starling, Lamprotornis regius
Also known as the royal starling, found in East Africa, these social animals exhibit a behavior known as "cooperative feeding" wherein the larger social group of starlings collectively nest and feed their young. Male and female birds share the same coloration, and the starling's feathers grow more vibrant as the bird ages.

Excerpted from *Feathers: Displays of Brilliant Plumage* by Robert Clark to be published May 2016 by Chronicle Books. Copyright © 2016 by Robert Clark. Reprinted by permission.

Robert Clark is an award-winning freelance photographer and frequent contributor to *National Geographic.* He lives in New York City.

Advances in transportation required disparate wheel designs.

BY RICHARD W. BULLIET

Wheel versus Wheel

COLOURBOX.COM

...H. T. Alken's 1831 depiction of steam-powered cars of the future. A View in Whitechapel Road; Background railroad wheelsets

In 1850, the steam engine was ranked as the world's greatest invention. By 1950, the wheel, a much older invention, had surpassed it. The advent of the electric motor and the internal-combustion engine partly explain the decline of the steam engine; but the spread of automobiles, trucks, and buses—not to mention grocery carts, bicycles, and roll-aboard luggage—played a greater role. In 1850, the wheeled vehicles that rumbled over the cobblestones of city streets and jounced along the rutted dirt roads of the countryside seemed neither new nor particularly ingenious.

The question of when and where the wheel first appeared did not excite much interest before the twentieth century, and even now it is hard to find comprehensive accounts of how wheels have been used for transportation in different times and places. Nor has it been widely recognized that wheels come in three strikingly different forms, each with its own history of invention. Two kinds, wheels that are fixed to the ends of an axle and turn in unison as the axle turns—the whole apparatus is called a wheelset—and wheels that rotate independently from each other on the ends of a stationary axle, date to between 4000 and 3000 BCE. They have thus been around for more than five thousand years. The third form, termed a caster, rotates on an axle and also pivots in a socket situated above it, the axis of pivoting being somewhat offset from the axis of rotation. Despite its technological simplicity, the caster seems to have come into use only three hundred years ago.

We encounter wheels of all three designs almost daily. Railroad and subway cars originally rolled on wheelsets, whereas road vehicles use wheels that rotate individually, mostly developed from an original form of two wheels rotating independently on the ends of an axle. And casters abound on wheelchairs, gurneys, laundry carts, dollies, baby strollers, and desk chairs.

Steering is key to the three different wheel designs. Locomotives and railcars cannot make sharp turns because, in the process of turning, the outer wheel covers a greater distance than the inner wheel and thus must make more rotations. Consequently, when the wheels turn in unison in a wheelset, the outer wheel is skidded or dragged around the turn. Railroad steering is accomplished by following rails, and railroads are designed with only very gradual curves.

Axles with independently rotating wheels do not have this problem, but a wagon equipped with four wheels on two axles still has a hard time turning unless the front wheels can change direction. Pivoting a front axle in its middle underneath a wagon was the most common way of changing the direction of the wheels until two hundred years ago, when alternatives were devised to allow each front wheel to pivot separately. Automobiles use these later modifications and thus can turn much sharper corners than can railroad cars.

As for the caster, if more force is applied to one side than the other, the wheels turn automatically in the desired direction. Grocery carts and wheelchairs typically combine casters in front with rear wheels that do not pivot, but dollies and desk chairs use only casters and can easily move in any direction.

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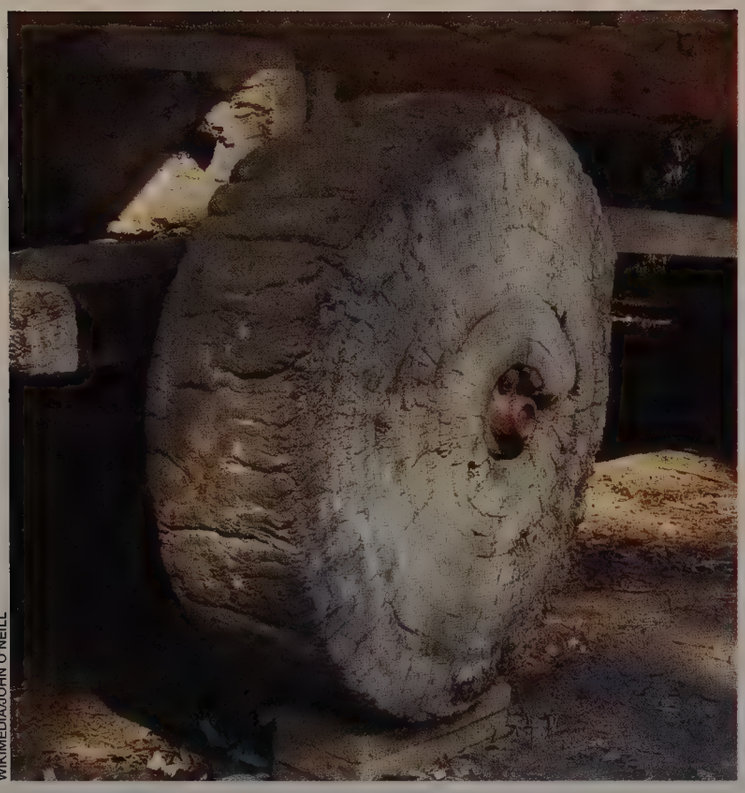
A depiction of an onager-drawn cart on the "Sumerian battle standard of Ur" (c. 2500 BCE)



WIKIMEDIA/JOHN O'NEILL

The earliest wheels were made of a solid piece of wood.

MUSÉE DES ARTS ET MÉTIERS, PARIS

Nicolas-Joseph Cugnot's three-wheeled steam-powered wagon was originally built in 1769; this reconstruction resides in Paris.

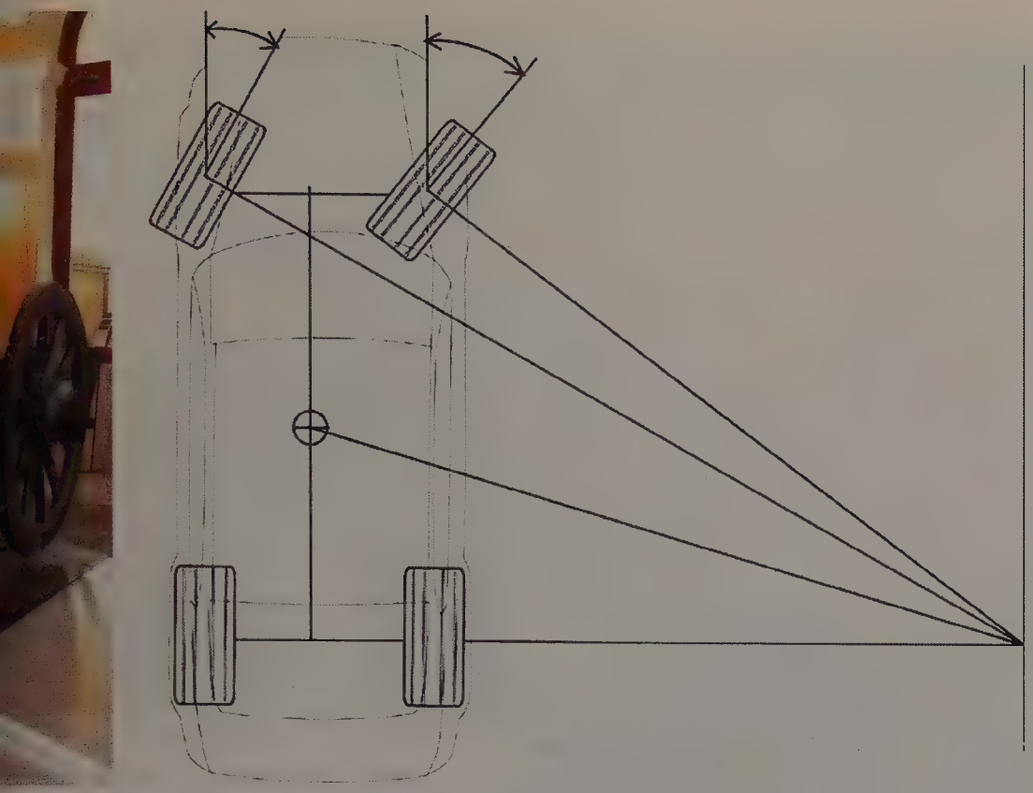
At the dawn of the European Renaissance in the fourteenth century, four-wheeled vehicles were not in common use anywhere in the world. Two-wheeled carts were easier to build, easier to steer, and mechanically more efficient, since two wheels turn with only half the friction of four. Even in Europe, the only world region that never abandoned the four-wheel concept, passenger wagons were used almost exclusively by noblewomen, the infirm, and the elderly. Noblemen rode horses as a sign of their elite warrior status, while eminent churchmen rode mules.

This situation changed dramatically over the next three centuries, in what might be called the carriage revolution. By 1650, from the Thames to the Danube, the use of four-wheeled passenger vehicles soared. The number of carriages in Britain, for example, could be counted on one hand in 1570, while the official tax totals in 1814 enumerated "23,400 four-wheeled vehicles paying duty to the government; 27,300 two-wheel, and 18,500 tax carts [inexpensive vehicles taxed at a lower rate]; a total of 69,200," which amounted to one vehicle for every 145 inhabitants.

As the numbers grew, so did the variety. European carriage makers and wheelwrights catered to every taste. In addition to such generic conveyances as "long wagons" for hauling freight and stagecoaches for transporting people, carriage makers turned out a dazzling array of designs. The differences among them involved size, weight, type of springs or suspension, steering mechanism, driver position, passenger capacity, seating arrangement, number of horses, and a galaxy of door, window, and top designs. By the mid-nineteenth century, the range of choices available had turned the carriage, or buggy (to use the American term), into a perfect billboard for displaying one's economic status or personal style, thus prefiguring the automobile culture that was to evolve in the twentieth century and that continues into the twenty-first.

In addition, the Europeans and Americans who made up the social elite in overseas colonies, or whose diplomatic or business duties compelled them to sojourn in non-Western lands, often used carriages to advertise the cultural and technological superiority of their home countries. In 1833, traveling biblical scholar John Kitto remarked that he "saw no wheel-carriages of any kind in Persia." Exactly fifty years later, however, diplomat Samuel G. W. Benjamin, the first American minister to Persia, reported that "the number of carriages owned by Persian and European gentlemen [in Tehran] is nearly five hundred, all imported."

Carriage building far outstripped road building, however. The problem of finding a road surface that would bear up under heavy traffic and iron-rimmed wheels was paralleled by the problem of finding a way to pay for road maintenance. Until new experiments with road building began to bear fruit in the mid-nineteenth century, the surfaces beneath the carriage wheels remained rutted, muddy, and poorly paved—if paved at all. This was particularly true in the countryside, but miserable roads existed even in major cities. In 1703, for example, during a trip south from London to Petworth, fifty miles away, the carriage carrying the Habsburg emperor Charles VI overturned twelve times on the road. And a half century later,



Ackermann steering, as diagrammed above, allows front wheels to turn at slightly different angles from each other.

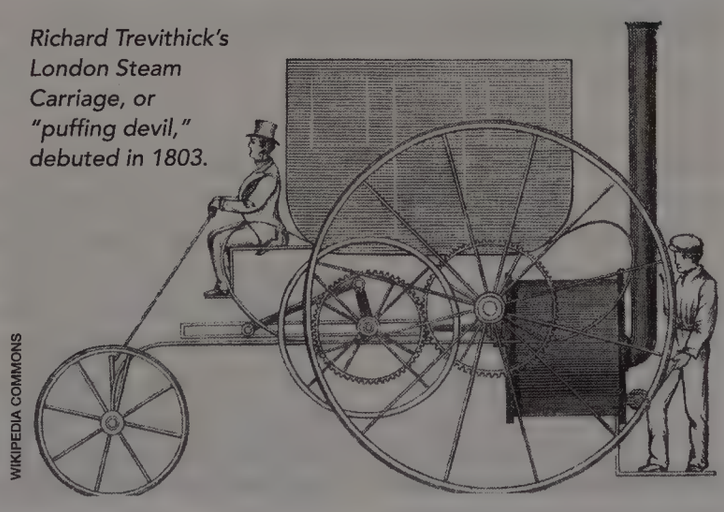
To begin to understand the evolution of modern motor transport from the vantage point of the wheel, we must consider the alternatives offered by the emergence of the two different wheel technologies in the fourth millennium BCE. The choice between wheels fixed to axles and independently rotating wheels that originated in that era reemerged in the industrial age to affect modern transport at a fundamental level. The wheelset, or fixed-wheel design, was invented first, perhaps as early as 4000 BCE, for use in copper mines situated in eastern Europe's Carpathian Mountains, which stretch westward from Romania, across western Ukraine, southern Poland, and northern Hungary, to Slovakia. The independently rotating–wheel design, very likely inspired by the wheelset, appeared a few centuries later, somewhere in southeastern Europe between the Carpathians and the broad plain north of the Black Sea, where people speaking Proto-Indo-European shared a set of technical terms for wagons with rotating wheels, but did not have a word for the wheelset.

In the absence of any archaeological traces of roads, we can assume that most wagons with fully rotating wheels moved cross-country over uneven dirt and grass. This would have required wheels of fairly large diameter, around thirty inches to judge from surviving examples. The stone floors of mines, however, could be as smooth and as straight as the miners chose to make them. Yet ore is extremely heavy, so the four-wheeled mine-cars pushed by the miners were no bigger than today's wheeled laundry carts and had comparatively small wheels, perhaps around one foot across. Given straight tunnels, flat stone floors, and the absence of draft animals, there was little need for steering. And it was better to use a wheelset than an axle with independently rotating wheels because when the former broke, the mine-car simply stopped; but having a single wheel come off, as commonly happened with independently rotating wheels, could dump the entire load of ore onto the tunnel floor.

Mine-cars continued to be pushed by European min-

Mile End Road, the major thoroughfare leading east from the entrance to the City of London at Aldgate, was described as "a stagnant lake of deep mud from Whitechapel to Stratford," a distance of four miles.

Roads outside Europe were at least as bad. In Washington, D.C., for example, the track between the Capitol and Thomas Jefferson's White House, a way labeled Pennsylvania Avenue on the map, was so crude that "every turn of your wagon wheel...is attended with danger." And the stagecoach that connected Capitol Hill with Georgetown, just five miles away, made a round trip twice a day "in a halo of dust...pitch[ing] like a ship in a seaway, among the holes and ruts of this national highway."



Richard Trevithick's London Steam Carriage, or "puffing devil," debuted in 1803.

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To these poor road conditions may be added the steadily growing problem of horse manure, blighting pedestrian activity. Ironically, as the condition of streets and roads became better, the accumulation of manure became worse. One estimate from the 1890s predicted that by 1950 London would be buried in nine feet of horse droppings, while another concluded that by 1930 manure would reach the third-story windows of buildings in Manhattan.

ers until the eighteenth century, when pit ponies and mules took over some of the work in Britain and elsewhere. Also by then, the idea had spread of using wooden tracks—which arose in the sixteenth century, if not earlier, and were later replaced by iron—to guide the cars and provide a smoother surface for them to roll on.

Outside the mining world, fixed-wheel vehicles were rare, though two-wheeled versions saw some use in the Roman Empire, and rustic oxcarts of this design could occasionally be found in southern Europe from Portugal to Turkey in the early twentieth century and were not unknown in India. Although the outer wheel had to be skidded around sharp corners, carts with solid fixed wheels were easier to build and more durable than those with independently rotating wheels, especially if the rotating wheels had spokes. Nevertheless, the two-wheeled, animal-drawn cart with independently rotating wheels was by far the most common form of wheeled transport, not just in Europe but from India and China to South America.

SOFTELS/WIKIPEDIA COMMONS

The Benz Patent Motorwagen, Velo, 1894

In 1712, Thomas Newcomen, a blacksmith in Dartmouth, England, invented the "Atmospheric Steam Engine," a massive, four-story-tall device designed to pump water out of flooded mines. Soon after, innovative thinkers began to imagine shrinking the device down to a size that could be put on wheels. They had three vehicular designs with which to work: the two-wheeled cart and the four-wheeled wagon or carriage, both of which were equipped with independently rotating wheels; and the four-wheeled mine-car, which rode on wheelsets and rails.

Since steam engines, no matter how compactly designed, seemed intrinsically to be constructions of great weight, balancing one on two wheels and a single axle was out of the question. In fact, no motor-vehicle design based on two wheels placed side-by-side saw the light of day until American entrepreneur Dean L. Kamen invented the Segway in 2001. As an alternative, however, it seemed feasible to add to a conventional cart design a pivoting third wheel placed either before or behind the two main wheels. This might not only help distribute the weight of the steam engine, but also facilitate steering. French engineer and mechanic Nicolas Joseph Cugnot pursued this idea with a vehicle that he built for the French army in 1769. To achieve a weight balance between the steam engine and the artillery or other heavy load that the vehicle was intended to pull, Cugnot put the boiler far forward and the steam engine itself directly over a single front wheel that could be turned, if one had sufficient strength, by means of a two-handed steering tiller. When the army rejected the design, the idea of balancing a steam engine on a single wheel died with it.

In 1803, however, Richard Trevithick, one of the pioneers of steam-engine and locomotive design, tried a different approach. His London Steam Carriage used the third wheel solely for steering. The weight of the engine and of the stagecoach-like passenger compartment rested on two huge rear wheels. The driver sat in front and steered the pivoting front wheel with a long, angled tiller of the type that had been in use for fifty years on three-wheeled Bath chairs at England's seaside resorts. Although Trevithick's contraption proved too uncomfortable and expensive for practical use, his vision aroused enough interest to spur a satirist to imagine what steam traffic on a London street might look like in the future (see page 26).

The motorized-tricycle concept did not die with the London Steam Carriage. In 1867, a practical steamroller went into production. Its engine's great weight, which was an asset rather than a liability given the vehicle's purpose, was divided between two rear wheels and a weighted and pivoting front wheel as wide as the vehicle. And in 1885, Karl Benz unveiled the Benz Patent Motorwagen, a pioneering internal-combustion automobile that used a precursor of the steering wheel to pivot its front wheel. Nevertheless, the future of motorized transport was destined to lie with four wheels rather than three. Steering presents the primary drawback to placing a steam engine on a four-wheeled base. When animals pulling a vehicle change direction in response to commands from the driver, they cause the device that connects them to the vehicle—either a central wagon beam or two shafts extending forward from the vehicle's axle or bed—to put turning pressure on the vehicle. While this kind of pressure works well for a two-wheeled cart with wheels that rotate independently of each other, it can produce only a shallow turn in wagons whose front axle is firmly fixed to the bottom of the vehicle. The rear wheels, wanting to continue forward in a straight line, prevent any sharper turn. If, however, the front axle is fixed to the bottom of the vehicle by a wooden or metal pin in its middle, it is free to pivot and change direction in response to the turning pressure exerted by the animals.

A freight truck, displayed at the Illinois Railway Museum, took inspiration from the wheels of mining carts.

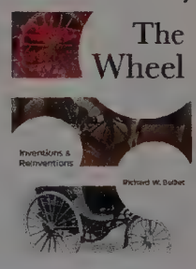
WIKIPEDIA/SEAN LAMB

Replace the animals with a motor engine, and changing direction becomes the task of the driver, who must turn the front wheels of a four-wheeled vehicle. This task demands great strength if a major portion of the vehicle's weight rests on the axle. (Anyone who has lost power steering while driving a car has experienced the sudden increase in how much force it takes to turn the steering wheel.) This is why Trevithick and Benz opted for a single front wheel bearing a minimal load. Yet instability problems can arise even with a front axle that pivots in the middle, particularly when making very sharp turns.

The earliest publicized improvement over steering a four-wheeled vehicle by means of a pivoting front axle came from the workshop of an engineer in Munich named Georg Lankensberger in 1818. Lankensberger asked his friend Rudolph Ackermann, a German-born carriage builder who had turned to lithographic printing after immigrating to England, to take out a patent on a device he had come up with. His friend complied, but put his own name on the application. Consequently, Lankensberger's invention has been called Ackermann steering to the present day. The core of the idea was to keep the front axle stationary in rounding a curve, but pivot each wheel independently at its end. Lankensberger' s system has two advantages. First, it allows the wheels to turn at different angles so that the outer wheel can follow a longer path around a corner than the inner wheel; and second, the vehicle is less likely to become unstable and turn over on sharp curves. Later improvements fine-tuned Lankensberger's design, and turning each wheel instead of the axle between them eventually became the standard approach for automobile designers.

Simultaneously, in the early nineteenth century, the steam locomotive evolved from the technological universe of mining, not of road transport. As part of their mining heritage, the locomotives and railcars that ushered in the railroad age used wheelsets instead of independently rotating wheels. This was possible because the tracks they traveled on, taken from mining practice, took the place of a steering mechanism. And the loads they were designed to carry consisted of heavy coal rather than comparatively light human passengers. Wheelsets were also desirable because the derailment that would be unavoidable if a single wheel broke or flew off its axle, a not uncommon phenomenon with carriages, presented a far greater threat to passengers and freight than did a flat spot that prevented a wheelset from rotating efficiently. Although railroads did eventually adopt a pivoting-wheel assembly, called a truck in the United States and a bogie in Britain, it normally consists of two wheelsets connected to each other beneath a central pivot rather than wheels rotating independently of each other on the ends of an axle.

Thus the railroad industry and the automobile industry came to be founded on competing notions of what a wheel is.



Excerpted from *The Wheel: Inventions and Reinventions* by Richard W. Bulliet. Copyright © 2016 Columbia University Press. Used by arrangement with the Publisher. All rights reserved.

JAHAN SALEHI

Richard W. Bulliet taught Middle Eastern history and the history of technology at Columbia University from 1976 to 2015. He is the author of *Cotton, Climate, and Camels in Early Islamic Iran: A Moment in World History*; *Hunters, Herders, and Hamburgers: The Past and Future of Human-Animal Relationships*; *The Case for Islamo-Christian Civilization*; *Islam: The View from the Edge*; and *The Camel and the Wheel*.

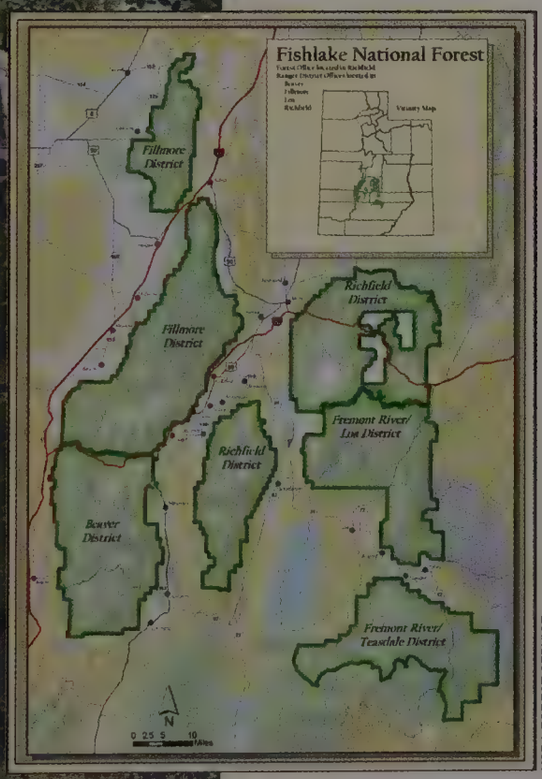
The Pando clone in central Utah's Fishlake National Forest is composed almost exclusively of mature stems that are dying off and are not being replaced.

Saving Pando

Humans are taking measured steps to rejuvenate an ailing giant.

BY PAUL C. ROGERS

Last fall, intrepid teenagers in groups of threes and fours fanned out across the Fishlake National Forest in central Utah to put their ideas to the test. The Ogden High School International Baccalaureate class, along with their instructors, came to a place in the forest to see and to learn about what is thought to be the world's largest living organism: a 106-acre clone of quaking aspen (*Populus tremuloides*) stems estimated to weigh thirteen million pounds. Though aspen are the most widespread tree species in North America, the deteriorating state of this clone may bear lessons not only for these students or for the fate of aspen continentally, but for human interactions with nature in general. How this clone came to be and its ultimate arrival in the present predicament is a story of evolving science and shifting stewardship; a partnership born of necessity and urgency.



USDA FOREST SERVICE

In 1968, forest ecologist Burton V. Barnes (1930–2014), professor in what is now the University of Michigan's School of Natural Resources and Environment, identified this huge clone by discerning the difference in annual patterns in leaf color and development from adjacent aspen stands. Twenty-five years passed before evolutionary biologist Michael C. Grant, at the University of Colorado-Boulder, named the clone "Pando" (Latin for "I spread") and dubbed this specimen the World's Largest Organism. In 2008, a team of researchers led by Karen Mock, associate dean of the Quinney College of Natural Resources at Utah State University, confirmed Barnes' original estimate of Pando's size, but also noted a curious ring of much smaller aspen clones surrounding the giant. How these patterns of genetic growth developed over time—perhaps one clone pushing the others aside, or opportunistic seedling establishment near the edges—continues to puzzle modern scientists. Moreover, though we have no dependable method for determining Pando's age,

PAUL C. ROGERS

we do know that this huge, genetically identical organism comprised of an estimated 47,000 stems (called ramets) originated from a single seed the size of a pepper grain. The nature of this beast causes us to re-examine what it means to be an individual specimen when what appear to be free-standing trees are actually small elements of a much larger being with a root system that exchanges life-supporting energy among ramets.

Traditional aspen science leans heavily on the fact that the species propagates via root sprouting, also known as suckering. In response to forest disturbance, such as wildfire, logging, or blowdown, aspen sucker profusely to initiate new cohorts. This rapid successional response favors aspen over competing vegetation in the early years, but eventually conifers outmuscle aspen for such resources as sunlight, water, and space. Not all aspen, as in the case of Pando, compete with conifers; some grow in nearly pure stands where disturbance does not play a major role. Instead, continuous asexual reproduction from thriving root systems produces patches of aspen stems growing, at any given time, in a variety of sizes and ages.

PAUL C. ROGERS

This six-inch-tall aspen sucker arising from the parent roots of Pando represents future "generations" of the giant clone. Repeated browsing by ungulates results in clipped tops and multiple stems.

USDA FOREST SERVICE/B. CAMPBELL

Stems of the same clone may stay connected for decades, although many separate over time.

In fact, recent research, such as that coming from Mock and her associates, clearly describes patterns of offspring indicative of regular seedling development—i.e. sexual regeneration. Both root suckers and seedlings have played a role in the life of Pando, though we don't fully understand the relative importance of each.

As the young scientists of Ogden High School quickly discovered, all is not well with Pando. A casual walk through this immense grove soon reveals a decided lack of young ramets, the lifeblood of any healthy aspen forest. The giant that thrives on continuous reproduction appears to have stopped reproducing. If this were a human community, it would be as if there were almost no babies, teenagers, young adults, or even middle-aged people. The Pando clone is made up almost entirely of senior citizens and, as would be the case were this a village, concern for the future of this western icon is well founded.

While we cannot age aspen clones with accuracy, we can determine the ages of stems by taking core samples, just as we do with most tree species. We know that the mature ramets of Pando are predominantly 100-120 years old; elderly specimens for aspen, but not for conifers in this region. The aspen lifestyle, or functional ecology, is to live short lives and reproduce quickly using carbohydrate energy produced in the leaf canopy and stored in the expansive root system. With such aggressive reproductive mechanisms in place, one would guess the clone abounds in young suckers. So, why is Pando missing these age groups?

One likely group of suspects threatening Pando are herbivores. Deer and cattle eat suckers soon after they emerge from the ground. Young aspen stems contain supple twigs loaded with nutrients intended for fast growth. A consistent pattern of herbivorous behavior, lasting over decades, has resulted in a very uneven stem demography. As with all tree species, death of old aspens occurs naturally from a variety of causes, such as internal decay, insect infestation, wind throw, and physical wounds from animals and humans, but mortality without replacement spells potential systemic collapse.

If Pando represents a natural system, possibly thousands

of years old, how did it come to this perilous state in so brief a time? There may be several contributing factors, but there's little doubt that people have played a role. Contemporary domestic cattle and wild ungulates are regulated by human agency. Further, over the past century we've been quite successful at reducing or eliminating apex predators that previously swayed herbivore numbers, movement, and habitat. There are economic incentives for keeping both livestock and game animal numbers high. A greater degree of control over livestock allows innovative grazing strategies to keep producers in business while concurrently preserving important resources. With wild game, day-to-day management is more difficult, but long-term populations may be manipulated through regulation and licensing. So, the "naturalness" of this system has been significantly altered over recent decades and the symptoms of decline are now becoming evident within Pando, which is considered a keystone species for numerous plants and animals. Similar aspen stories are playing out across the American West; a combination of drought-plagued forests and overabundant herbivores sets up a slow march toward system failure.

PAUL C. ROGERS

These mule deer have found ways to crawl under eight-foot-tall fences to access nutrient-rich aspen suckers. The difficulty and expense of maintaining fences present significant challenges to sustaining Pando's future.

Natural resource issues often involve "messy" solutions, in which multiple players represent divergent philosophies, and degrees of intrusion and ecological outcomes are far from certain. An iterative approach for combating complex socio-ecological issues is to develop tentative approaches based on limited information and to monitor progress, making adjustments along the way based on new findings. So-called "adaptive management" prevents the employment of policies assumed, without supporting data, to have positive outcomes, and their pursuit to potentially deleterious ends. When managers implement actions without ongoing monitoring, they miss opportunities to learn from either successes *or* mistakes.

In 2013, a plan was developed by Utah State University, USDA Forest Service, Utah Department of Wildlife Resources, and Grand Canyon Trust to enclose about fifteen acres (fourteen percent) of Pando with eight-foot fencing and to conduct experimental treatments within that area. It was hoped that outcomes of this experiment would provide a course of action for sustaining Pando's future. The goal was to allow new aspen stems to grow beyond the height of ungulate reach, as well as to determine which treatment method resulted in the best growth response for money spent. Monitoring began just after the fence was erected and an annual remeasurement is ongoing. Thirty-five sample plots, each containing two 100- by 6-foot transects, were located inside and outside the fenced area and various combinations of treatments—burning, juniper removal, and partial cutting—were applied on both sides. Inside the fenced area, control plots also tested the effect of only fencing without any other treatments. In addition to tallying different aspen stem sizes and status (alive or dead), field personnel noted browsing level on small aspen and counted both deer and cattle scat to gain measures of animal use and presence. It was important for researchers to clearly understand what actions were effective and which animals, if any, were causing recruitment loss.

Preliminary test results are beginning to shed light on Pando's situation. Since the 2013 fence was erected, browsing inside the fence has essentially stopped—although not as completely as expected—and aspen suckers are growing between two and three feet annually in both treated and untreated areas within the fence. One hundred percent browsing and almost no surviving regeneration is taking place outside the fence. Initial data indicate a slightly higher rate of aspen regeneration where sites were purposely disturbed versus those that were only protected. There was no significant difference among manipulations (burning, juniper removal, and partial cutting) in terms of their regeneration response. Overall, it is clear that the temporary fence is having a

PAUL C. ROGERS

Experimental burning within an ungulate exclosure was conducted in 2014 to clear undergrowth and stimulate aspen suckering.

positive effect on recruitment success, even in control plots where no active manipulation, other than fencing, was undertaken.

Apparent success after the first year of monitoring prompted USDA Forest Service officials to greatly expand in 2014 an older fenced area. This original fence was constructed in 1992 after earlier trials of clear-cutting aspen within a section of Pando resulted in a complete loss of forest cover and regeneration due to browsing animals. After one year, the expanded fenced area showed little positive response, though there is evidence that mule deer have found ways to crawl under older, deteriorating portions of this fence. In fact, monitoring conducted by the visiting high school students over a twelve-acre portion of this larger exclosure revealed only one young aspen stem. Students also spotted deer within this protected area. Given current numbers of live mature trees, this plot would need at least twenty-two young stems to replace the current overstory, or canopy, of Pando. This number assumes, however, that none of the new recruits die before maturity; in reality, there is great attrition over the lifespan of aspen. Thus, the number of recruits should be double or triple the number of mature trees they replace in order to maintain the overstory. As the mortality of larger aspen trees continues, it further reduces total clone leaf area. Fewer leaves means reduced photosynthesis, which produces carbohydrates banked in the roots—the "fuel in the engine" for future sucker production. The stop-gap fencing is intended to promote juvenile stem survival in order to stymie this negative feedback loop by replacing decaying portions of this immense organism. By continually taking the pulse of Pando's regenerative capacity, and remaining open to course corrections where the data warrant change, a sober strategy for saving Pando seems to be in place.

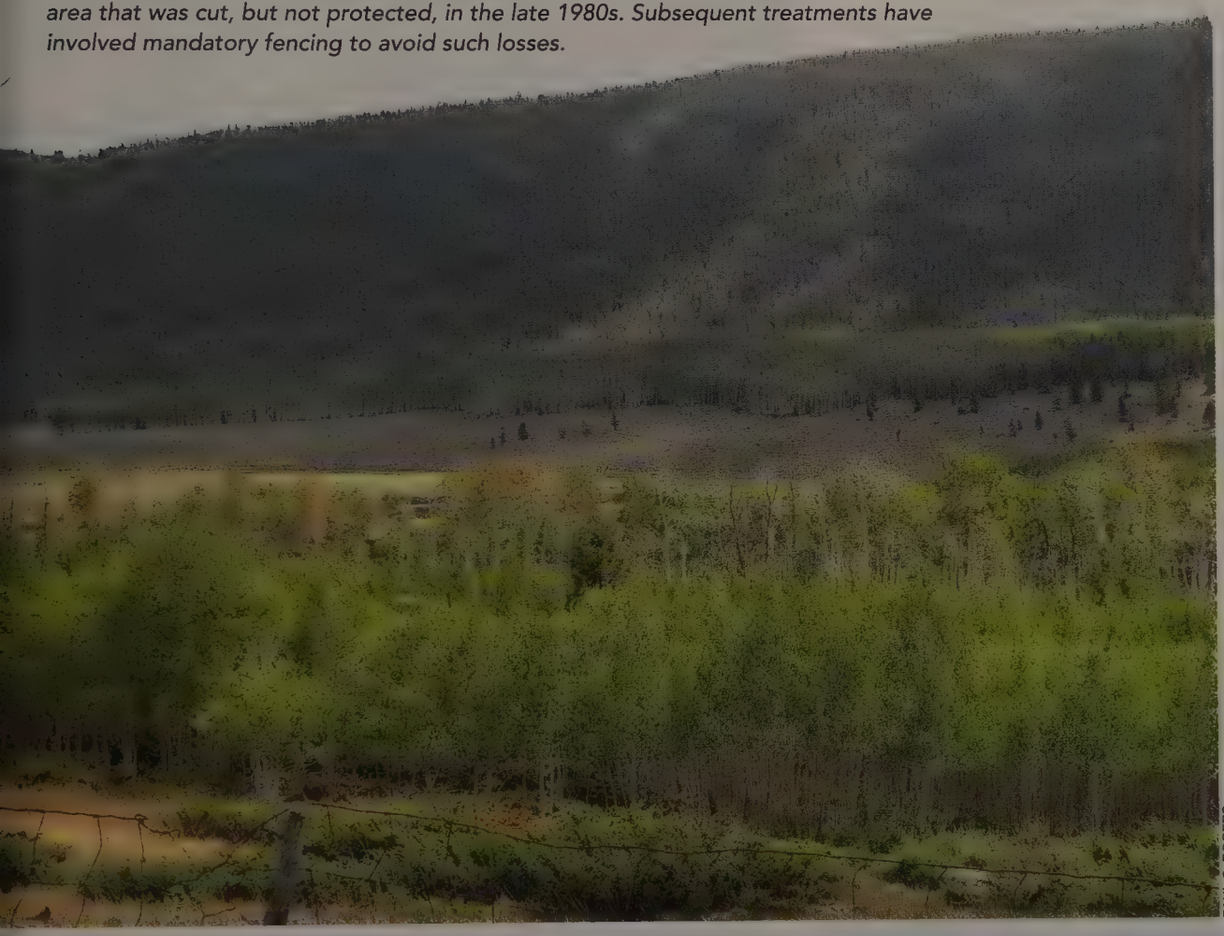
The Ogden High School students who prowled the forest floor last fall were probing basic research questions. How is plant diversity related to aspen cover? Do soil properties affect ramet health? What is the relationship between tree age and size; can one predict the other? Lessons learned at Pando not only add to their intellectual growth, but have the potential to inform future aspen stewards. Conservationist Aldo Leopold advised, "To keep every cog and wheel is the first precaution of intelligent

PAUL C. ROGERS

Though cattle are excluded from portions of Pando, short-term access in early summer and autumn, alongside continuous deer browsing, appears to be keeping all young aspen growth in check. The US Forest Service and partners are collaborating to reduce animal grazing and allow successful aspen recruitment before aging canopy stems die off.

tinkering." If a single plant of such size and putative age were to collapse now, we should regard this as a faltering of our society to preserve that which has survived the ages.

Pando probably arrived at its current state due to negligence in human decisions regarding livestock, wildlife, or both. Prior to fencing, based on circumstantial evidence of browse levels and scat deposits, cattle, deer, and possibly elk reduced the ability of the clone to survive without intervention. Presumably, there is a threshold beyond which further death of overstory trees decreases the ability of root systems to produce enough offspring to survive even with low levels of ungulate herbivory. It appears we are at that point. Current efforts to fence Pando piecemeal are showing positive results, although continual browsing in unprotected areas leaves little hope that peripheral portions of the clone will sustain themselves.



Pando is visible in the middle ground, while the non-forested foreground depicts an area that was cut, but not protected, in the late 1980s. Subsequent treatments have involved mandatory fencing to avoid such losses.

PAUL C. ROGERS

Across the West, quaking aspen face myriad challenges, such as fire suppression, drought, warming temperatures, development, and hydrologic re-engineering. Where herbivory is problematic, it exacerbates these problems. For example, drought-induced instances of mature aspen die-off increases the pace of clonal collapse where few young trees survive browsing. Still, there are many places where healthy communities persist, so we should use caution in projecting the ills of a single locale across the entire region. Moreover, solutions found at this scale, such as fencing out large herbivores, are not feasible on much larger landscapes due to cost, public outcry, or policy restrictions.

The value of aspen ecosystems reaches far beyond the beauty and elegance of a single clone or even the entire species. Quaking aspen, as the most dominant broadleaf in a region of conifers, is widely recognized as a foundational element with numerous obligate plants and animals. Therefore, thriving or failing aspen clones engender cascading effects on biodiversity at large. This exceptional being called Pando represents not only a milestone of single organism size, but a potential laboratory for broader aspen stewardship, as well as an essential forest component for creatures that reside in its shade.

Diverse organizations are coming together to save Pando. We will surely learn as we go and, hopefully, remain vigilant as we make inevitable adjustments along the way. The greatest optimism is lodged in the simple acts of curiosity and discovery found in the minds of budding scientists. To wander the woods, to daydream, to form hypotheses, and to test them—sometimes succeeding, sometimes failing—presents a model for our society to embrace. Pando represents vital links: plant to animal, soil to tree, water to roots, humans to environment. Pando's peril points to broader disconnections, while its perseverance spells hope.

Paul C. Rogers is an adjunct associate professor in the Department of Wildland Resources at Utah State University, an associate at USU's Ecology Center, and director of the Western Aspen Alliance (http://western-aspen-alliance.org/). He worked for sixteen years for the U.S. Forest Service conducting monitoring activities. His primary area of study has been human impacts on vegetation in the western United States.

Around the Country

The Greeks

Experience 5,000 years of Greece's history and culture through the words and objects that defined life in its ancient past. Now at The Field Museum in Chicago until April 10, *The Greeks—Agamemnon to Alexander the Great* presents perspectives on Greek civilization from its origins in Neolithic villages through its expansion during the conquests of Alexander the Great. The exhibition draws from the collections of twenty-one museums throughout Greece, making it the largest exhibition of its kind to tour North America in twenty-five years. It showcases more than 500 artifacts, many of which have never been displayed outside of Greece, including enigmatic stone figurines from the Cycladic Islands, gold funerary masks from Bronze Age tombs, classical marble statues of Greek poets, athletes, and heroes, and brightly painted ceramic vases featuring scenes from Greek mythology and daily life. Explore epic stories from the point of view of the ancient Greeks themselves, including men and women known to us through historical accounts, mythological tales, and the archaeological record.

The Field Museum
1400 South Lake Shore Drive, Chicago, Illinois
312-922-9410 • www.fieldmuseum.org

This gold diadem, fashioned in the shape of a myrtle wreath, was worn by Queen Meda in the fourth century BCE. It is one of the remarkable artifacts on view now in the exhibition "The Greeks—Agamemnon to Alexander the Great."

ARIZONA

Phoenix

Arizona Science Center
Ongoing: **"Get Charged Up."** Visitors at the exhibition can see what happens when you put your hands on science. Humans are naturally curious and the science of observation helps us to understand the natural world around us—how things work and why.
600 East Washington Street
602-716-2000
www.azscience.org

CALIFORNIA

Los Angeles

California Science Center
Ongoing: **"Journey to Space: The Exhibition."** Examine the challenges and innovative solutions required for human space exploration, including the very real dangers astronauts face during their missions high above the Earth. Get a feeling for what space is like, how we are learning to live and work in space, and how we are preparing for bolder and more distant missions.
Exposition Park
700 Exposition Boulevard
323-SCIENCE (323-724-3623)
www.californiasciencecenter.org

Natural History Museum of Los Angeles County
Ongoing: **"Visible Vault: Archaeological Treasures From Ancient Latin America."** In this unique permanent exhibition, more than 600 fascinating artifacts and treasures from ancient America are on view, illustrating the sophistication and diversity of the civilizations that thrived throughout the Americas prior to European exploration.
Exposition Park
900 Exposition Boulevard
213-763-DINO
www.nhm.org

San Diego

San Diego Natural History Museum
Opening March 19: **"Whales: Giants of the Deep."** This exhibition's unique blend of science, storytelling, and innovative interactive displays gives visitors the opportunity to discover more about whales, which are some of the world's most elusive creatures. Developed and presented by the Museum of New Zealand Te Papa Tongarewa, the exhibition features two fully-articulated sperm whale skeletons, and showcases amazing and rare specimens from Te Papa's whale collection, one of the largest in the world.
Balboa Park
1788 El Prado
619-232-3821
www.sdnhm.org

COLORADO
Denver
DENVER MUSEUM OF NATURE AND SCIENCE
Through May 8: **"Chocolate: The Exhibition."** Chocolate. The word conjures up visions of candy bars, hot fudge sundaes, and rich brownies, yet its rustic origins extend back thousands of years. In this new exhibition, trace the story of the "food of the gods," from its earliest cultivation among the ancient peoples of the rain forest to its status today as the world's favorite sweet. Immersive exhibits, fun interactives, and detailed replicas and objects place chocolate under the lenses of science, history, and popular culture.
2001 Colorado Boulevard
303-370-6000
www.dmns.org

CONNECTICUT
New Haven
PEABODY MUSEUM OF NATURAL HISTORY
Ongoing: **"Hall of Minerals, Earth, and Space."** This permanent exhibition is designed to foster an appreciation for the wonders of our planet and solar system. Visitors are introduced to the processes that shape the earth—earthquakes, volcanic eruptions, and collisions with meteors—and to global changes in the continents, oceans, and atmosphere throughout geologic time.
Yale University
170 Whitney Avenue
203-432-5050
www.peabody.yale.edu

DELAWARE
Wilmington
DELAWARE MUSEUM OF NATURAL HISTORY
Ongoing: **"Nature Nook."** The interactive Nature Nook is a place where young children can explore animal habitats while having fun. Step inside a cave, walk through a woodland, enter an eagle's nest, and lots more!
4840 Kennett Pike
302-658-9111
www.delmnh.org

FLORIDA
Gainesville
FLORIDA MUSEUM OF NATURAL HISTORY
Ongoing: **"Our Energy Future."** Explore the museum's newest permanent exhibition. It is full of tips about reducing energy use at home, and features hands-on activities. Learn about alternative energy sources, the rooftop solar array that powers part of the museum, and more.
University of Florida,
Cultural Plaza
SW 34th Street and Hull Road
352-846-2000
www.flmnh.ufl.edu

GEORGIA
Atlanta
FERNBANK MUSEUM OF NATURAL HISTORY
Through July 31: **"Wild Music."** Whales compose, bullfrogs chorus, songbirds greet the dawn, and people everywhere sing and dance. Music is all around us, produced by creatures large and small. Explore sound and music in nature and in life through whimsical, hands-on activities.
767 Clifton Road NE
404-929-6300
www.fernbankmuseum.org

HAWAII
Honolulu
BISHOP MUSEUM
Opening March 19: **"Lele O Nā Manu, Hawaiian Forest Birds."** This exhibition highlights the rich and diverse natural history of endemic Hawaiian forest birds, their preeminence in traditional Hawaiian culture, and the dire need for their conservation.
1525 Bernice Street
808-847-3511
www.bishopmuseum.org

IDAHO
Idaho Falls
MUSEUM OF IDAHO
Ongoing: **"Race For Atomic Power."** Learn about the dramatic scientific and political adventure that occurred in Idaho's own backyard—including information about the first usable amounts of electricity produced by a nuclear reactor, the first city to be powered by nuclear energy, the birth of the nuclear navy, and many other important advances in nuclear power.
200 North Eastern Avenue
208-522-1400
www.museumofidaho.org

LINDT & SPRÜNGLI, SWITZERLAND

Most large-scale chocolate manufacturers run their factories like science laboratories. Precision instruments track temperature and moisture levels and regulate the timing of automated processes within the factory. "Chocolate: The Exhibition," now open at the Denver Museum of Nature and Science, gives visitors the opportunity to learn more about the making of the world's favorite sweet.

MEMBERSHIP HAS ITS REWARDS

Institutions marked with participate in the Passport program run by the Association of Science-Technology Centers (ASTC). If you're a member of a participating museum or science center, you may receive free admission at nearly 350 other museums and science centers around the world.

See www.astc.org/passport for more information.

Roughly a third of all humans are infected with the parasite *Toxoplasma gondii*. Studies suggest that infected men become more reckless, break more rules, and dress more sloppily. Infected women become more sociable and wear more expensive clothing. Both have slower reaction times and get in more car accidents. Pictured here is a digital rendering of this parasite, which is on view in the exhibition "The Secret World Inside You" at the American Museum of Natural History in New York City.

MASSACHUSETTS

Cambridge

HARVARD MUSEUM OF NATURAL HISTORY

Now open: **"Marine Life."** The centerpiece of the exhibition—a floor to ceiling re-creation of life in New England's coastal waters—immerses visitors in the astounding diversity and dynamic interplay among animals in marine communities just off local shores. As models of glowing jellies, a giant sea turtle, and other sea animals appear to swim above their heads, museum visitors will learn about new research and explore displays of real fishes, mollusks, crustaceans, corals, and other marine organisms selected from the world-renowned collections of Harvard's Museum of Comparative Zoology.

26 Oxford Street
617-495-3045
www.hmnh.harvard.edu

MINNESOTA

Minneapolis

BELL MUSEUM OF NATURAL HISTORY

Ongoing: **"Under the Fig Leaf: Rainforest Research."** In this permanent exhibition, explore the rainforest and learn about rainforest-related research being done by Bell scientists.

University of Minnesota
10 Church Street, SE
612-624-7083
www.bellmuseum.umn.edu

MISSOURI

Saint Louis

SAINT LOUIS SCIENCE CENTER

Ongoing: **"Experience Energy."** Learn about the different forms that energy can take, see how energy becomes electricity, and learn why energy efficiency makes a difference. The Experience Energy gallery also presents alternate methods of electrical generation and ideas to conserve energy.

5050 Oakland Avenue
800-456-SLSC
www.slsc.org

NEW MEXICO

Albuquerque

NEW MEXICO MUSEUM OF NATURAL HISTORY AND SCIENCE

Ongoing: **"The Hall of the Stars."** This permanent exhibition helps to explain how the night sky is organized. Rather than just showing the sky visible on any given night of the year, the Hall of the Stars allows visitors to see all of the year's stars and constellations in the same way that a world map allows us to visualize the whole globe.

1801 Mountain Road NW
505-841-2800
www.nmnaturalhistory.org

NEW YORK

New York

AMERICAN MUSEUM OF NATURAL HISTORY

Through August 14: **"The Secret World Inside You."** Our bodies are home to approximately 100 trillion bacteria living inside us and on us—a vast community known as the microbiome. This exhibition explores the rapidly evolving science that is revealing the complexities of the human microbiome and reshaping our ideas about human health, offering new perspectives on common health problems including allergies, asthma, and obesity.

Central Park West at 79th Street
212-769-5100
www.amnh.org

Tupper Lake

THE WILD CENTER, NATURAL HISTORY MUSEUM OF THE ADIRONDACKS

Ongoing: **"Wild Walk."** A trail of bridges leads high above the Adirondack forest where visitors can walk over the tree tops and explore the stunning natural environment from a new perspective. The recently-opened Wild Walk includes a four-story twig tree house, swinging bridges, a spider's web where guests can play, and an oversized bald eagle's nest at the highest point where visitors can perch and imagine life as one of the raptors.

45 Museum Drive
518-359-7800
www.wildcenter.org

NORTH CAROLINA

Durham

MUSEUM OF LIFE AND SCIENCE
Ongoing: **"Hideaway Woods."** This new nature playspace is a two-acre, forested learning environment featuring treehouses, a flowing streambed, and fanciful nature sculptures. Connected by rope bridges, the treehouse village encourages you to flex your body and imagination while viewing the world around you from a new perspective.
433 West Murray Avenue
919-220-5429
www.ncmls.org

Raleigh

NORTH CAROLINA MUSEUM OF NATURAL SCIENCES
Through March 27: **"Extreme Mammals."** This eye-opening exhibition explores the diversity of the biggest, smallest, and most amazing mammals that have ever roamed the Earth.
11 West Jones Street
919-707-9800
www.naturalsciences.org

OREGON

Eugene

MUSEUM OF NATURAL AND CULTURAL HISTORY
Ongoing: **"Site Seeing: Snapshots of Historical Archaeology in Oregon."** From a nineteenth-century working-class family in Portland to a Chinese mining community in Jacksonville, this exhibition tells the stories of five historical sites recently excavated by museum archaeologists.
1680 East 15th Avenue
541-346-3024
natural-history.uoregon.edu

PENNSYLVANIA

Philadelphia

THE ACADEMY OF NATURAL SCIENCES OF DREXEL UNIVERSITY
Through May 30: **"Tarantulas: Alive and Up Close."** Tarantulas have a reputation that precedes them—terrifying, fast, hairy, scary—the biggest, baddest, and most fearsome of all spiders. In this new hands-on exhibition, visitors come face-to-face with a stunning array of live tarantulas—fangs and all. Get the facts on why tarantulas are so hairy as you venture through an air current that simulates the sensitivities of a hairy spider. Explore a tarantula burrow and get your picture taken with these live eight-legged beasts!
1900 Benjamin Franklin Parkway
215-299-1000
www.ansp.org

TEXAS

Houston

HOUSTON MUSEUM OF NATURAL SCIENCE
Through September 5: **"La Virgen de Guadalupe: Empress of the Americas."** She's been a symbol of hope, protection, and comfort to her followers for almost 500 years, but why? What is it about her that has inspired millions throughout the Americas? Today, her image represents not only a great miracle, but the identity of a nation of believers. Trace the story back to its origins in this new exhibition.
5555 Hermann Park Drive
713-639-4629
www.hmns.org

UTAH

Salt Lake City

NATURAL HISTORY MUSEUM OF UTAH
Through May 1: **"Geckos."** Geckos are incredibly adaptable and have conquered habitats from balmy tropical beaches and lush rainforests to frigid mountain slopes and parched deserts. More than 1,200 species range from shadowy, nighttime hunters with bulging eyes and squawking voices to bold nectar-eaters that scamper around in daylight, adorned in neon colors. Come meet live geckos from around the world, and explore interactives that allow you to experience gecko night vision, listen to gecko voices, and try to spot camouflaged geckos.
301 Wakara Way
801-581-6927
nhmu.utah.edu

WASHINGTON

Seattle

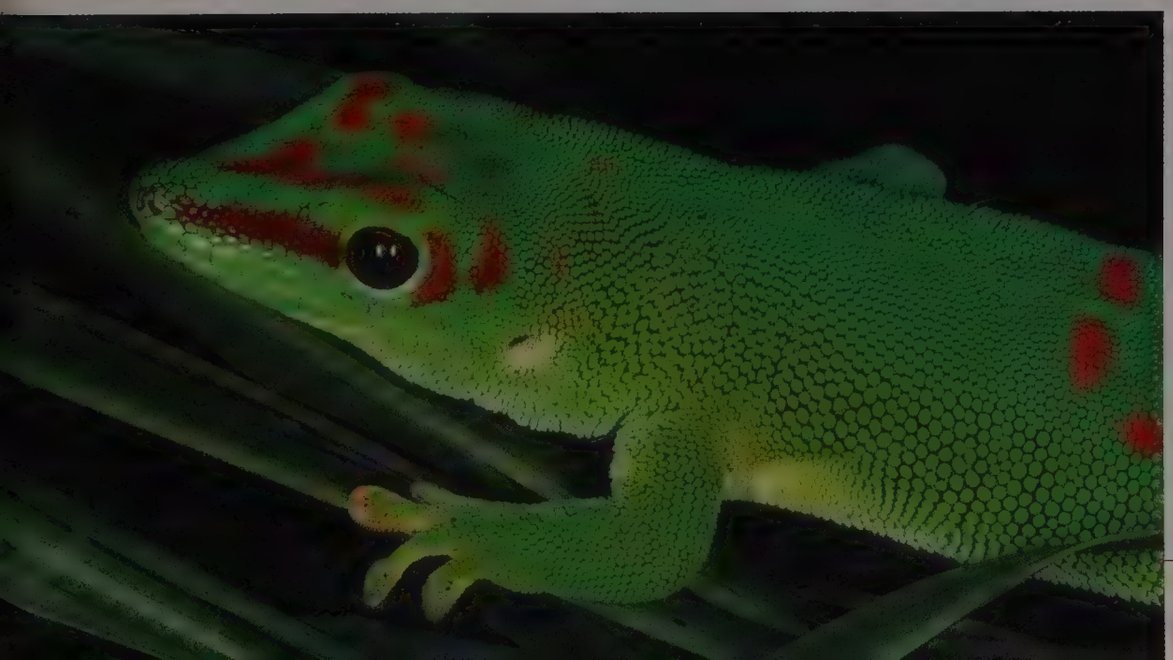
PACIFIC SCIENCE CENTER
Through May 1: **"Math Moves!"** This exhibition uses a variety of hands-on activities to make experimenting with concepts at the heart of math memorable and fun.
200 Second Avenue North
206-443-2001
www.pacsci.org

WISCONSIN

Milwaukee

MILWAUKEE PUBLIC MUSEUM
Ongoing: **"Crossroads of Civilization."** This permanent exhibition explores how the ancient civilizations of Africa, Europe, and Asia came together to form an epicenter of complex culture, creating not just a physical crossroads, but an intellectual one as well. The exhibition brings the ancient world to life by presenting over 200 artifacts from the museum's collections.
800 West Wells Street
414-278-2702
www.mpm.edu

Bulging eyes, sticky toepads, incredible night vision, disposable body parts—welcome to a gecko's world! See this giant day gecko and others in the exhibition "Geckos" at the Natural History Museum of Utah in Salt Lake City.



© AMNH; BILL LOVE

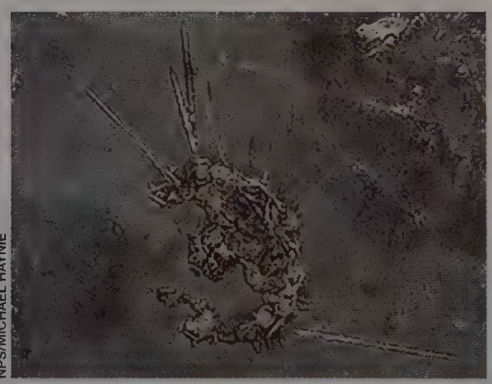
Marine Remains in the Mountains

Plant species flourish around an exposed fossil reef in the Guadalupe Mountains.

Lying across the Texas–New Mexico state line, the imposing Guadalupe Mountains rise above the surrounding Chihuahuan Desert to a height of 8,749 feet at Guadalupe Peak. Guadalupe Mountains National Park is on the Texas side of the line, and the Lincoln National Forest is on the New Mexico side.

The national park, so designated by Congress in 1972, consists of 86,367 acres. There are eighty-five miles of hiking trails, from easy to extremely rugged. There is an accessible 0.7 mile asphalt trail at the Visitor Center. The trails pass by a wide variety of plant communities that together contain more than 1,000 species of ferns and flowering plants. Most visitors head to the McKittrick Canyon Trail located just inside the northeastern boundary of the park, a few miles west of U.S. Highways 62 and 180. Another entrance is at Dog Canyon in the northernmost part of the park at the end of New Mexico Highway 137.

The main reason for making the Guadalupe Mountains a national park was to highlight and preserve Capitan Reef, perhaps the finest example of an ancient marine fossil reef anywhere in the world. Capitan Reef was formed 260–270 million years ago when a vast ocean covered much of Texas and New Mexico. Over millions of years, algae, sponges, and myriad other lime-secreting organisms precipitated from the ocean, eventually forming the 400-foot-long Capitan Reef. Long after the reef's formation, the ocean water began to evaporate, and the reef was buried under a thick blanket of sediments. In due time, mountain-building exposed the Capitan Reef in three mountain ranges. The exposed parts of the reef in these mountains rise dramatically above the Chihuahuan Desert. The reef is shaped like a horseshoe, with its southeast extremity exposed in the Glass Mountains near Alpine, Texas. The reef then extends underground northward, circling above the town of Carlsbad, New Mexico, before heading southwestward, becoming exposed again in the Guadalupe Mountains. From here the reef again is buried and curves southeastward, becoming exposed once more in the Apache Mountains north of Van Horn, Texas.

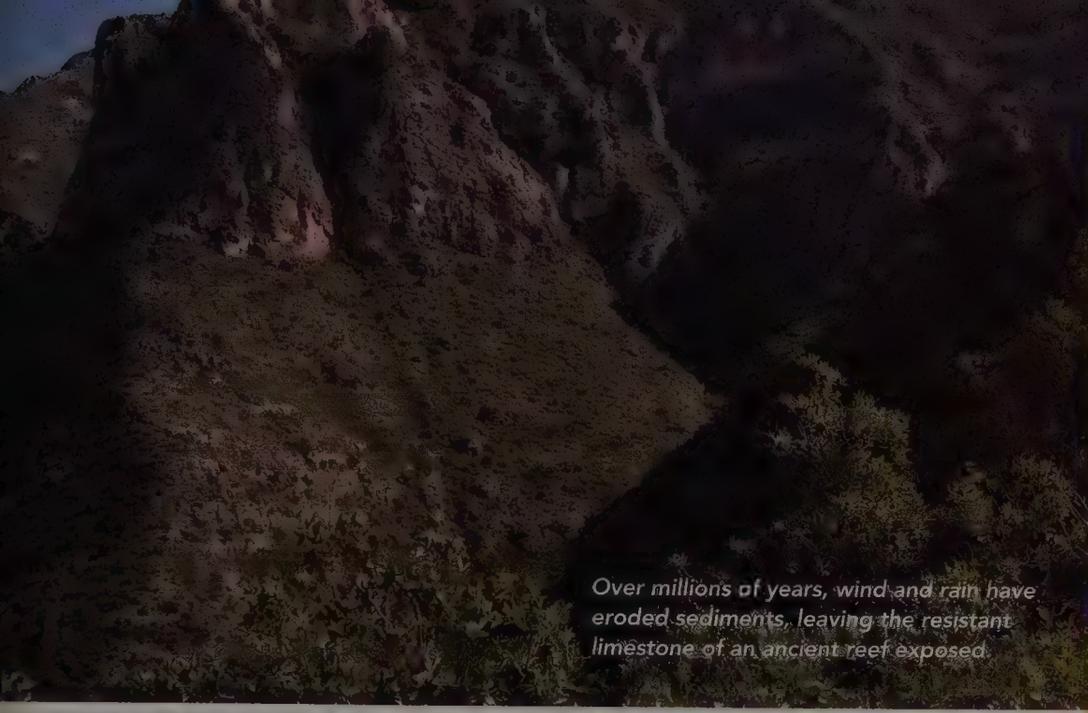


NPS/MICHAEL HAYNIE

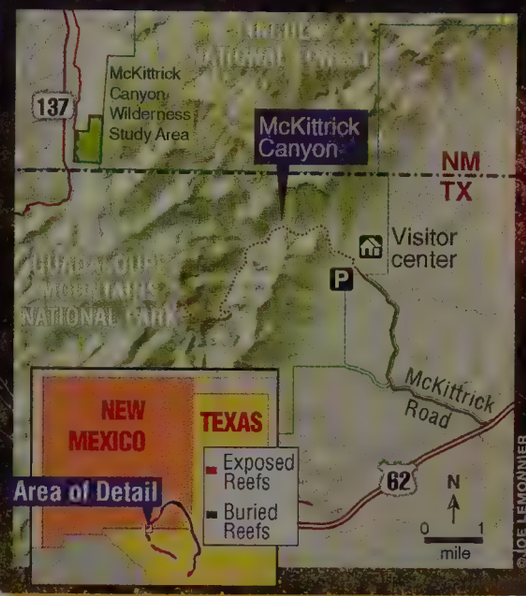
Inhabitants of the ancient, rocky sea bottom included sea urchins.

For those interested in seeing and learning more about Capitan Reef, take the rather strenuous 8.5 mile Permian Reef Trail from the McKittrick Canyon trailhead. This trail climbs 2,000 feet and will introduce you to the great array of fossils in the reef. Before hiking the McKittrick Canyon Trail, you might want to get in condition by taking the 0.9 mile McKittrick Canyon Nature Trail in the foothills. This trail passes mostly through desert and desert grassland communities.

The main McKittrick Canyon Trail will take you through all the major plant communities, depending on how far you wish to hike. The first part of the trail gives you a close look at the desert and desert grassland communities. In a short while, you will come to the mouth of McKittrick Canyon



Over millions of years, wind and rain have eroded sediments, leaving the resistant limestone of an ancient reef exposed.



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VISITOR INFORMATION:
Guadalupe Mountains National Park
AC 60, P.O. Box 400
Salt Flat, TX 79847
1-915-828-3251
www.nps.gov/gumo

NPS PHOTO/COOKIE BALLOU

NPS

*The long, narrow leaves of the desert willow (*Chilopsis linearis*) give it its common name, but it is not a true willow. It is beautiful when in bloom, and provides valuable nectar for hummingbirds, butterflies, bees, and other insects.*

where a montane scrub community exists. If you continue to follow the trail into the canyon, you will cross McKittrick Creek twice on your way to Pratt's Cabin, permitting you to examine a stream community. In this shady, rocky, limestone canyon, there are a few wet areas on the side of the cliff where water seeps through cracks in the limestone. A neat community of seep plants may be seen here. Otherwise, the limestone cliffs are dry and rugged, and many plants find a home in the cracks of the limestone and on the rocky slopes above the creek.

The round trip to and from Pratt's Cabin is nearly five miles. This cabin, built in 1931–32 out of local limestone, is where petroleum geologist Wilbur Pratt and his family once lived and fell in love with the area; in 1949 Pratt donated 5,632 acres to the National Park Service. The trail continues one mile beyond Pratt's Cabin to the Grotto. From here the trail begins a climb through a piñon-juniper woodland to McKittrick Ridge, at an elevation of 7,716 feet. By now, the trail also passes through a mixed woodland community. If you want to reach the highest elevations in the park where ponderosa pine dominates, you may follow the McKittrick Canyon Trail to its junction with Tejas Trail. This latter trail, rough and rocky, heads south, eventually coming to side trails to Hunter's Peak (8,368 feet), Guadalupe Peak (8,749 feet and the highest peak in Texas), and El Capitan (8,085 feet). The Tejas Trail can also be accessed from the Dog Canyon Campground.

The desert community is extremely dry, with few trees scattered among the sparse vegetation. In places where grasses are abundant, the habitat is a desert grassland community. Several cacti live in the desert community, including tree cholla, pencil cholla, hedgehog cactus, pincushion cactus, Graham's prickly pear, Lindheimer's prickly pear, and Texas hedgehog. Large succulents in this community are banana yucca, New Mexico agave, green sotol, and Trans-Pecos beargrass. A few scattered trees in the desert community are white thorn, viscid acacia, catclaw mimosa, and ocotillo. Shrubs include agarita, evergreen sumac, and feather peabush. Among perennial herbs are large-flower onion, Fendler's beardtongue, antelope sage, blanket-flower, spreading thoroughwort, broom snakeweed, desert dandelion, lemonweed, paperflower, Rocky Mountain zinnia, and purple curlleaf. In the desert grassland community, common grasses are black grama, blue grama, Chino grama, cane beardgrass, hairgrass, tobosa, little

NPS

Unique desert and mountain vegetation combinations such as New Mexico agave, alligator juniper, and ponderosa pine are common on the high ridges of the Guadalupes.

bluestem, burro grass, spike dropseed, and slim tridens.

At the mouth of McKittrick Canyon is a montane scrub community, still dominated by shrubs, woody-based perennials, cacti, agaves, yuccas, and sotol, along with many species from the desert grassland community. The montane scrub community is characterized by dry, windy conditions and rocky, gravelly soils. The community is often on a southeast-facing slope. The vegetation depends in part on the elevation and in part on the amount of moisture available. Among the many species present are Fendler's ceanothus, alderleaf mountain mahogany, Apache plume, mock orange, rock spiraea, sandpaper oak, cliff fendlerbush, desert sumac, Wright's silktassel, resinbush, Utah serviceberry, and wildflowers that include spreading fleabane, woolly white, spectacle pod, Texas croton, woolly dalea, blue sage, Fendler's beardtongue, ridgeseed spurge, and Parry's spurge.

In somewhat drier areas, often at a higher elevation than the montane scrub community, a habitat dominated by pine and junipers is evident. The pine is Colorado piñon, and it is joined by alligator juniper, oneseed juniper, and redberry juniper. Gambel oak is usually present. Other plants include the rare Trans-Pecos Indian parsley, along with the more common antelope horns, annual wild buckwheat, Wright's thelypody, redwhisker clammyweed, purple sand verbena, and grasses including Indian ricegrass, Plains lovegrass, green sprangletop, and bush muhly.

Botanists are in their glory identifying the plants that grow from crevices in dry limestone cliffs. Among the many species I saw were Guadalupe least daisy, Parry's wild petunia, cliff nama, McKittrick's false pennyroyal, Guadalupe milkwort, Texas vervain, Kunth's onion, Utah fendlerbush, western white honeysuckle, Guadalupe valerian, spreading fissurewort, mountain mock thelypody, Plains greasebush, Wright's stonecrop, and several ferns including Plummer's cliff fern, New Mexico cliff fern, Eaton's lipfern, woolly lipfern, villous lipfern, star cloak fern, purple cliffbrake, spiny cliffbrake, and Wright's cliffbrake. A mixed woodland community is one where coniferous trees and broadleaf trees co-mingle. Texas madrone is one of the spectacular plants in this particular community. Also usually present are gray oak, pointleaf manzanita, and Wright's silktassel, along with piñon pine and alligator juniper.

Above 6,000 feet elevation is a beautiful forest of ponderosa pine, Douglas fir, southwestern white pine, and quaking aspen. Other plants may include Havard's false willow, longleaf cologania, Ft. Bowie prairie clover, Rothrock's snakeroot, smooth blue aster, whitemargin pussytoes, trailing fleabane, little cryptantha, and nodding onion.

ROBERT H. MOHLENBROCK is a distinguished professor emeritus of plant biology at Southern Illinois University Carbondale.

HABITATS

Streams and Other Wetlands Although most of the Guadalupe Mountains National Park consists of dry habitats, McKittrick Creek usually has flowing water, and there are occasional pools of water along the creek. Trees growing creekside include little walnut, narrowleaf willow, Goodding's willow, peachleaf willow, velvet ash, netleaf hackberry, and lanceleaf cottonwood. There are a few shrubs including desert willow and desert snowberry. Other plants occurring here and there are Geyer's onion, splitleaf brickellbush, canyon drymary, early shaggytuft, clasping dogbane, bract milkweed, Lindheimer's morning-glory, and New Mexico copperleaf. Standing pools of water usually have several sedges, including swamp sawgrass, several species of *Eleocharis* (spikerushes), hardstem bulrush, three-square, and several kinds of *Carex*.

Seepage Areas A unique habitat consists of seep areas where water, forced through cracks in the limestone, keeps shaded cliffs continuously wet. Here are found the very rare Chaplin's golden columbine, wild celery, southern maidenhair fern, and maidenhair spleenwort.

Gypsum Areas Deposits of gypsum have built up in several areas of the national park. Most plants cannot survive in a concentration of gypsum, but some species are adapted to this harsh habitat. These include Trans-Pecos honeysweet, shrubby honeysweet, small-headed blanket-flower, false broomweed, sand fiddleleaf, Stevens' fiddleleaf, James' seaheath, gypsum milkvetch, and southwestern ringstem.

SKYLOG BY JOE RAO

Dates Uncertain

METROPOLITAN MUSEUM OF ART/ ROBERT LEHMAN COLLECTION

The Last Supper, *c. 1325-30, by Ugolino di Nerio*

The date for Valentine's Day is the same every year, as is the date for Independence Day in America. The dates for other holidays and events that some of us celebrate or observe change annually. According to ecclesiastical rules, the vernal equinox is fixed on March 21, even though worldwide from the years 2004 through 2103 it will occur no later than March 20. This year, 2016, depending on which time zone you live in, the vernal equinox (the first day of spring in the Northern Hemisphere) occurs on March 19 or 20. The Moon is full on March 23, the first one of spring. It's designated as the Paschal Moon, because Pesach, or Passover, was always kept on the fourteenth day of the first month, Nisan, of the old Jewish calendar, which began with the full moon. The first Sunday coming after the Paschal Moon is usually Easter Sunday, as will be the case this year, on March 27. But the ecclesiastical date assumed for the Full Moon may not coincide precisely with the astronomical one. In practice, Easter is determined from other formulae such as epacts, which are based on the nineteen-year metonic lunar cycle (also known as the cycle of golden numbers). In the year 2038, the equinox falls on March 20 with a full Moon the next day, so astronomically, Easter should fall on March 28 of that year. In reality, however, as mandated by the rules of Roman Catholic and Western Protestant churches, Easter in 2038 will be observed as late as it can possibly come, on April 25. Eastern Orthodox churches, which use the Julian calendar, will observe it on April 12.

Joe Rao is a broadcast meteorologist and an associate and lecturer at the Hayden Planetarium in New York City (www.haydenplanetarium.org).

MARCH NIGHTS OUT

1 Last Quarter Moon at 6:11 P.M. EDT

7 Early this morning, a very thin waning crescent Moon, less than forty hours before new phase, is situated about three degrees to the upper left of Venus, but both objects are barely above the east-northeast horizon during dawn. Venus is still a bright precursor of the Sun, but this planet's height at sunrise declines significantly in March. As viewed from latitude 40° north on this morning, Venus rises only about 50 minutes before the Sun and climbs to only 5° up by 20 minutes before sunrise.

8 New Moon at 8:54 P.M. EST. Today there will also be a total solar eclipse. To see it, you'll have to journey to Indonesia (which is west of the International Date Line, where the calendar date is March 9). Hawaii and most of Alaska will see a partial eclipse near sunset this afternoon. Alaskans will see the passing New Moon take only a small scallop out of the Sun, but from Honolulu seventy percent of the Sun's diameter will be eclipsed at 5:36 P.M. HAST. If you live in the visibility zone of this eclipse, the most important thing to keep in mind is never to look at even a portion of the Sun directly without proper viewing glasses or special lenses for telescopes and binoculars, otherwise permanent eye damage can occur.

Also on this date, Jupiter arrives at opposition, meaning it's opposite to the Sun in our sky. Therefore, Jupiter rises around the time the Sun sets, shines highest about midnight and sets around sunrise. Opposition is also when Jupiter is closest to the Earth for the year, appearing biggest and brightest. Look for it in the east as the blue sky darkens. Jupiter is quite impressive this month, burning at magnitude -2.5, nearly three times as bright as Sirius, the brightest star in the sky.

13 Daylight Savings Time returns on this second Sunday in March. Except in the states of Arizona and Hawaii, and the Canadian province of Saskatchewan, clocks are to be moved forward one hour at 2:00 A.M.

15 First Quarter Moon at 1:03 P.M. EDT

16 Early this morning, Mars will appear a mere 0.15° northeast of the third magnitude double star Graffias (Beta Scorpii). Examine them with binoculars. Mars rises within a half hour of 12:15 A.M. local time during March. Of magnitude +0.3 at the start of the month, the planet will then appear twice as bright as its nearby "rival," the ruddy star Antares. By midmonth, Mars will match the yellow-orange star Arcturus both in color and brilliance (magnitude -0.1), and by month's end its brightness will have more than doubled compared to the start of the month. This brightening is due to the largest monthly relative decrease in Mars' distance of its current apparition. Its telescopic disk grows noticeably by 26 percent in apparent size during March, but the Martian north pole is tilted only 10° toward Earth, making the shrinking polar cap hard to observe even in a large telescope.

20 At 12:30 A.M. EDT the Sun appears to cross the celestial equator moving north. Spring begins in the Northern Hemisphere and autumn begins in the Southern Hemisphere. Note that for the central and western states, the vernal equinox will occur before midnight on the calendar date of March 19.

21 As the sky darkens this evening, face east to see the nearly full Moon with brilliant Jupiter sitting a couple of degrees to its left.

23 Full Moon at 8:01 A.M. EDT. This Full Moon will also undergo a penumbral eclipse which favors the Pacific Ocean; Hawaii sees it high in the sky during the middle of the night. Across North America, the eclipse takes place between midnight and dawn. The farther east one goes, the closer the time of moonset coincides with the moment that the Moon enters the penumbra. At maximum (4:47 A.M. Pacific Time), a subtle but perceptible "smudge" or tarnishing will be evident along the Moon's southern limb.

29 In the early morning hours, take note of the waning gibbous Moon forming a rather wide triangle with Mars and Saturn. The two planets are roughly ten degrees apart with the Moon in between and standing well above them. Saturn rises around 12:45 A.M. local daylight savings time and will reach the southern meridian, its highest and best position for observing soon after the start of morning twilight. Through a telescope, Saturn is spectacular! Its famous rings are tilted 26.2° toward Earth.

31 Last Quarter Moon at 11:17 P.M. EDT

Fluke: *The Math and Myth of Coincidence* by Joseph Mazur, Basic Books, 2016; 288 pages, $26.99

The year is 1929, and a young woman is strolling along the banks of the Seine in Paris, browsing bookstalls on a sunny afternoon. She spots a used anthology of fairy tales among the spines, haggles for a bargain, and hands her purchase to her husband, commenting how much she loved this book when she was much younger. Her husband opens the book and says "indeed you did"—for there on the flyleaf is his wife's name in pencil, along with her childhood address. Her personal copy, lost long ago, has somehow traveled across the Atlantic to meet her decades later.

Coincidence or fate? Such remarkable intersections of circumstance are so surprising that we tend to assign them supernatural importance, a sign of some underlying plan or meaning, and even the most skeptical among us find them hard to understand. Joseph Mazur, an emeritus professor of mathematics at Marlboro College, is not so baffled. Coincidences like the uncanny reappearance of a childhood book are to be expected, he demonstrates, as a consequence of the laws of probability and statistics applied to otherwise random events.

Take for instance the "birthday problem," a favorite example in elementary statistics classes. How many people must be in a classroom to have a better than fifty-fifty chance that two classmates have the same birthday (month and day)? The answer is twenty-three, and the more people you add, the higher the probability becomes—it's over 90% by the time the class size reaches forty! Surprising at first, the result, as Mazur explains, can be proven with no more than simple mathematics.

One reason we find it surprising that only twenty-three people are needed is that we tend to regard the coincidence as "someone else has the same birthday as me, even though there are 364 other days in the year on which they could be born." But the actual result is not that someone shares *our* particular birthday, just that there are two people in the room who share *some* birthday.

With so many people in the world, and so many events happening every day, it's not surprising that highly unlikely events occur somewhere, sometime. Mathematically predictable, these events catch our notice and make for tales of remarkable coincidence. The meaning we attribute to serendipity, in other words, is often of our own making, not a manifestation of nature's plan.

Coincidences also occur, of course, because there are more connections than we are aware of in our society. The woman in Paris was an avid reader, so she was more likely than the average person to frequent the bookstalls along the Seine. Her mother was an artist, with friends in Paris, to whom she might have lent a book her daughter left at home. So, in that sense, there was an unseen moving finger guiding the book back to the hand of its former owner. The patterns that inevitably emerge in enormous numbers of random events will surprise us, but we should think of the world, Mazur advises, as being both very small and very large at the same time.

The journey quest—a hero's voyage toward a remote and significant goal—is a core plot device in much of the world's best folklore and literature. Think of Jason and the Golden Fleece, Odysseus and his homeland, and, more recently, Sal Paradise in *On the Road* or W.P. Inman in *Cold Mountain*. The journey quest at the heart of William Stolzenburg's new book features an unconventional hero to be sure, a three-year-old mountain lion who remains unnamed throughout. Yet readers will find it both compelling and insightful, a worthy addition to the narratives of young adventurers in search of riches, love, and meaning.

Heart of a Lion: *A Lone Cat's Walk Across America* by William Stoltzenburg, Bloomsbury, 2016; 256 pages, $27.00

Heart of a Lion is a non-fiction tale of endurance and resilience. Its feline protagonist was part of a wild population of cats, numbering several hundred in 2009, that had re-established themselves in the Black Hills of South Dakota after being nearly extinguished by farmers and ranchers in the early years of the twentieth century. Late in 2009, a young male lion headed east, perhaps in search of a mate, and on December 5 it was sighted by a police patrol in Champlin, Minnesota, just north of Minneapolis. Sporadic cougar sightings continued eastward for more than a year, through the Upper Peninsula of Michigan, across the St. Mary's River into Ontario, and eventually across the St. Lawrence River into northern New York State, where the trail headed south.

On June 5, 2011, our lion was seen padding through a suburban yard in Greenwich, Connecticut, and six days later, a little after midnight on June 11, its journey came to an end when it was struck and killed by an SUV on the Wilbur Cross Park-

way. It had walked halfway across the continent, dodging traffic, swimming rivers, and skirting millions of homes and farms—probably all in a tragic search for a mate. What made this quest so notable, aside from the distance traveled and the hardships endured, was that the trip was so well documented by twenty-first century technology: police dashcams, automatic trail cameras, DNA analysis of scat and fur by rangers, and a host of eyewitnesses carrying smartphones. You can still find videos of the errant cat posted on the web (just Google "Champlin cougar" or "Greenwich cougar").

To nature journalist Stolzenburg, the young lion's journey provides not only a rousing survival story, but also an occasion to think seriously about the porous boundaries between wilderness and civilization in present-day America. As the lion continues eastward, Stoltzenburg detours frequently to describe tensions between those eager to restore large mammals to ancient habitats and those who view the beasts as threats to livestock, pets, and people. Though the lion never speaks, there are plenty of voices you will hear—conservationists, biologists, ranchers, homeowners, and a few enthusiasts who believe that breeding populations of cougars already exist in the eastern United States (though no female cougars have ever been seen in the wild east of the Mississippi). Stoltzenburg's thoughtful and gripping narrative, in the end, is less about the sad heart of a lion on a fruitless quest, and more about the hearts and minds of the humans whose territory it traversed.

The Cabaret of Plants:
Forty Thousand Years of Plant Life and the Human Imagination
by Richard Mabey, W.W. Norton & Company, 2016; 374 pages, $9.95

The Cabaret of Plants, as its name suggests, is a diverse collection of entertaining performances—in the form of short, lively essays on matters botanical. British nature writer Richard Mabey has taken as his overall theme the surprising and creative ways in which humans and plants interact, and has put together a program that is both delightful and enlightening.

The human-plant relationship, he points out, is an odd coupling, for plants are so different from us that they might as well be extraterrestrial beings. They sit quietly in one place; they have no brains or central nervous systems; they do not vocalize, or move, at least in the way we animals do. Yet they are undoubtedly alive and, as Mabey remarks at the outset, "they have agendas of their own." Some of them can respond to stimuli, like the tipitiwichet—a name applied by eighteenth century botanists to the Venus flytrap (*Dionaea muscipula*), whose leaves can snap shut to trap insects. Many plants communicate with one another, sometimes through airborne chemicals that warn of danger, other times through signals sent through roots, a system that one ecologist called a "wood-wide web."

What goes through the minds of plants—if they have consciousness in any sense—we may never know. Mabey's essays, therefore, are devoted to how plants have affected the consciousness of humans over the ages, from cave artists who carved leaves on bone 15,000 years ago to modern painters like Margaret Mee, who led an arduous expedition into the flooded forest of the Amazon to view the moonlight cactus, *Selenicereus wittii,* which only blooms on one night of the year.

Prehistoric art, Mabey notes, depicts animals much more often than plants. Perhaps early hunter-gatherers, despite their animistic view of nature, were not willing to grant equal status to plants as living beings.

We moderns, like Margaret Mee, are more easily charmed by botanical life. Some charmers are familiar, everyday plants, like the dancing daffodils of Wordsworth's Lake District. Others, more exotic, evoke awe or marvel, like the giant sequoias of the California coast, or the "vegetable wonder," the giant water lily *Victoria amazonica,* another native of the Amazon, whose massive pad can reach six feet in diameter. A specimen of that "Queen of Lilies" grown at Kew Gardens in London in the 1840s drew crowds of 10,000 people daily, not just to see the mammoth leaf floating in a specially constructed tank, but also to watch as its blossom opened at about 2:00 each afternoon, emitting a sweet, fruity odor reminiscent of melon, strawberry, and pineapple, before closing in the early evening.

Every act in Mabey's botanical review highlights a talented performer. He writes of Methusalah trees thousands of years old, whose very hardiness challenges our sense of time and mortality. He spins the lore of the ginseng plant, whose roots resemble little humans, and whose high-priced extract is supposed to cure almost anything that ails you. Despite generations of claims about its efficacy, however, modern medicine finds no significant benefit to the stuff: Mabey quotes fellow plant maven Euell Gibbons as acknowledging that all he got from drinking expensive ginseng tea was a "feeling of luxurious self-indulgence."

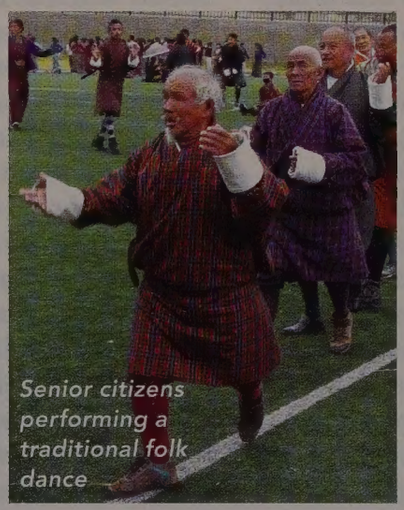
Laurence A. Marschall is a professor of physics at Gettysburg College in Pennsylvania. His most recent books, coauthored with Stephen P. Maran, are Pluto Confidential: An Insider Account of the Ongoing Battles over the Status of Pluto *and* Galileo's New Universe: The Revolution in Our Understanding of the Cosmos *(both BenBella Books, 2009).*

One hundred monks rehearsing a cham *(sacred dance)*

ENDPAPER BY KAREN GREENSPAN

State-sponsored Happiness

Last November, citizens of the tiny Himalayan nation of Bhutan were in a frenzy preparing for the sixtieth birth anniversary of their previous king, His Majesty the Fourth Druk Gyalpo (Dragon King) Jigme Singye Wangchuck, who had reigned from 1972–2006. This wise, benevolent, and innovative leader brought Bhutan into the modern age by implementing such public policies as free public education, free healthcare services, well-planned business development, internet connectivity, and vigorous environmental protections. In an unparalleled move, he launched the drafting of a constitution and shifted the country to democracy. He then abdicated the throne to his eldest son, King Jigme Khesar Namgyel Wangchuck. According to some, the king made this move because he did not want his son to be unexpectedly thrust into the role of leadership as he had been at age sixteen when his father died suddenly.



Senior citizens performing a traditional folk dance

The Fourth Druk Gyalpo is probably most renowned, however, for introducing the concept of Gross National Happiness (GNH)—the government policy that measures the growth and development of the country by the happiness and contentment of its people. At the core of the policy are four priorities—equitable and sustainable development, protection of the environment, preservation and promotion of Bhutan's unique cultural heritage, and provision of good and responsive governance.

In honor of the king's birthday, the entire country observed three days of celebration from November 9-11. Because Bhutan is a Buddhist country, prayers and rituals were woven into the festivities. The Je Khenpo, High Abbot and spiritual leader of the country, wrote a special *zhabten*—a prayer for the long life of an individual composed by a senior spiritual figure whose power of speech is considered capable of turning word into reality. Other prayers and texts were to be recited across the country in *dzongs* (fortresses), monasteries, temples, and seminaries. At Changlimithang Stadium in the capital city of Thimphu, one hundred monks rehearsed a special *cham* (sacred dance) called Zheng Zhi Pem that is a component of the Longevity Ritual. An elaborate ceremonial procession with military, monastic, and government officials, as well as an honor guard of one thousand army personnel, was presented three times to His Majesty.

Because the people of Bhutan are so happy—more than ninety-one percent of the population were scored as happy in a 2015 GNH survey, www.grossnationalhappiness.com—many of them wanted to participate in showing gratitude for His Majesty's leadership. The currency of gratitude in this land of happiness is dance. At The Royal Academy of Performing Arts, the artists rehearsed their own folk dance presentations inside the studio while, on the court outdoors, they directed a group of 138 bespectacled civil servants who showed up to learn and perform a dance for the king. Schools from all over the country prepared traditional folk dances, as did a group of senior citizens. When one of the queens—the king married four sisters during one ceremony—called for 108 (the number that makes up the complete prayer cycle for Buddhists) women to volunteer to perform a dance, 200 turned out. The Bhutanese had readied multiple venues throughout the capital for all the events and entertainers, including a group of hip-hop dancers. The release of thousands of colorful, biodegradable balloons and three cake-cutting ceremonies capped the celebrations.

My takeaway, after witnessing these events in November, is that a government's focus on the happiness of its people can be a powerful transformative force, an instrument for positive social change.

Karen Greenspan, a New York City-based dance writer, researches and observes contemporary and traditional dance forms in the United States and abroad. A former professional dancer, she is a frequent contributor to Natural History. *Most recently, she wrote about traditional and unscripted forms of dance in Myanmar in "A Romantic in Search of the Authentic" [10/2015].*

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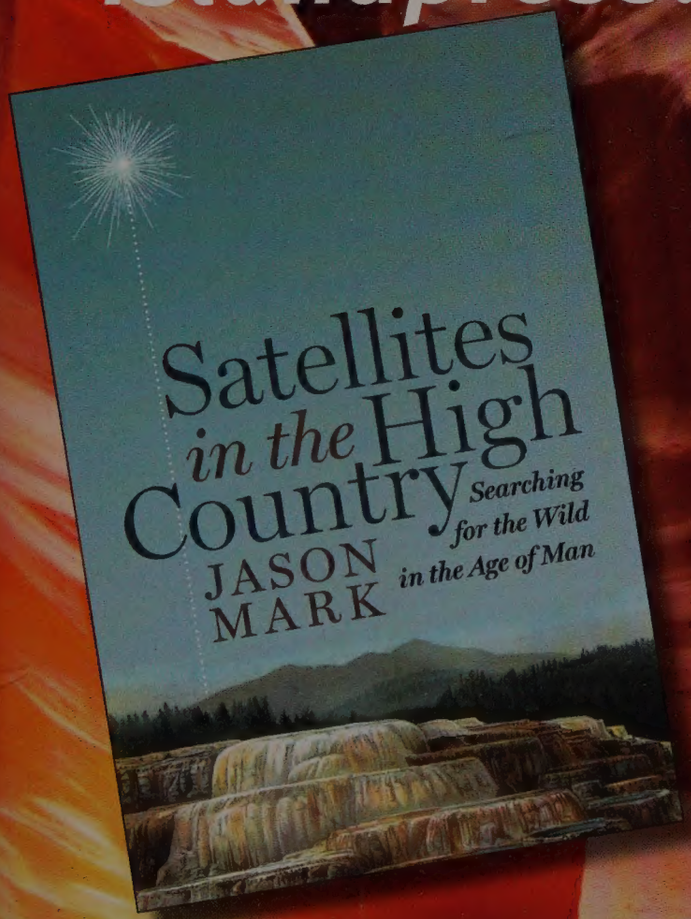

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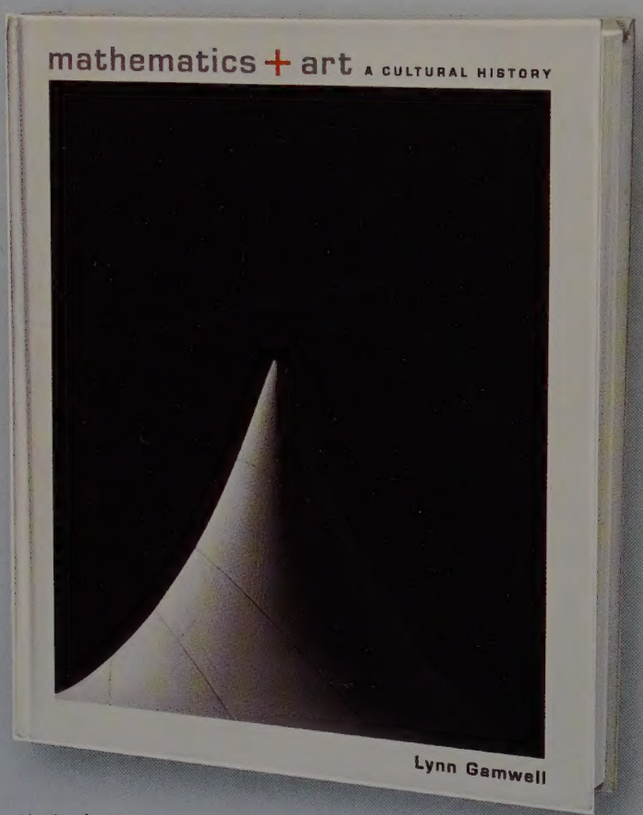
Mathematics and Art

A Cultural History

Lynn Gamwell

With a foreword by Neil deGrasse Tyson



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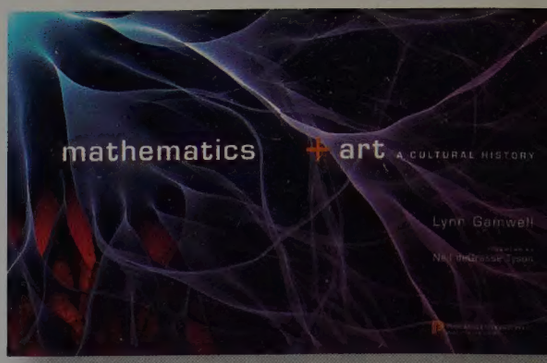

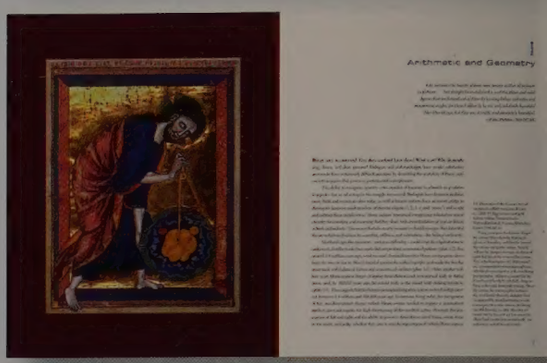

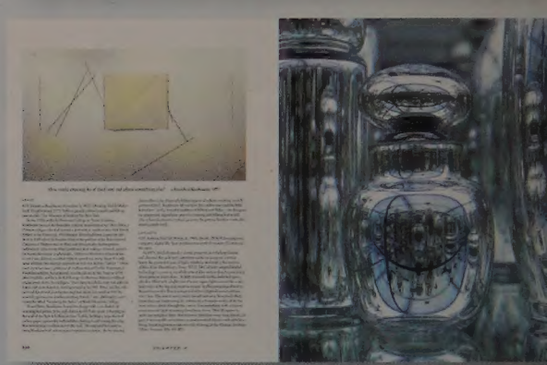

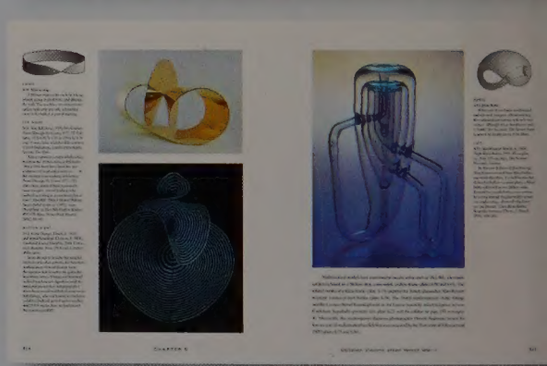

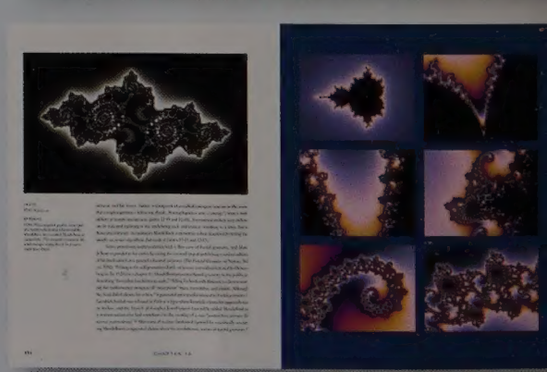

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